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THE ROYAL SOCIETY OF TASMANIA

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
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TASMANIA

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Publication of this volume was generously supported by the Government of Tasmania and the University of Tasmania.

THE DEVELOPMENT OF 1080 USE FOR RABBIT CONTROL IN TASMANIA

by M. Statham

(with one text-figure and two tables)

Statham, M. 2005 (16:xii): The development of 1080 use for rabbit control in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 139: 1–6. ISSN 0080–4703. Tasmanian Institute of Agricultural Research, PO Box 46, Kings Meadows, Tasmania 7249, Australia.

The Tasmanian Department of Agriculture, together with the CSIRO Wildlife Survey Section pioneered the use of sodium fluoroacetate (Compound 1080) in Australia following reports of experimental trials in the USA. This paper, with information taken primarily from Department of Agriculture files, describes the development of 1080 use in Tasmania from 1949 to the last major effect on practices in other states in 1964.

Key Words: 1080, rabbit, sodium fluoroacetate, Tasmania, history.

INTRODUCTION

Compound 1080 has a controversial history in Tasmania, as it is often used to control native macropods and brush-tailed possums. These species have increased dramatically in numbers since the 1960s as a result of agricultural development. In response to public opposition to its use, the Government adopted a plan to reduce the level of 1080 use with a phase out by 2015 (Community Leaders Group 2001), and on 22 September 2004 the Premier of Tasmania, Paul Lennon, announced there would be a ban on 1080 use in State forests by December 2005 (*Examiner* 23 September 2004). Tasmania is the first state to make this decision, which represents a long-term change in government and public thinking.

The early history of the discovery and development of sodium monofluoroacetate (Compound 1080) in Europe has been described by a number of authors, including Ward (1946), Atzert (1971) and Connolly (2004). Prior to the Second World War most rodenticides were produced in Europe and the beginning of the war led to a chemical screening program to develop new rat and mouse control agents for use in the USA. One of the most promising chemicals found during this evaluation was Compound 1080. In order to protect use of the material by the US government and to ensure that the compound could not be patented by anyone other than the researcher involved, the rodenticidal properties of 1080 and its effects on a number of other species including dogs were described by Kalmbach (1945) (cited by Connolly 2004). Other groups were working on this and related compounds (e.g., McCombie & Saunders 1946), and the effects of 1080 on a range of other species were soon reported (Ward 1946, Ward & Spencer 1946, King & Penfound 1946). Because of its toxicity and lack of taste, an approach was made to the manufacturer, Monsanto, to restrict sales and ensure the chemical would be shipped only to "responsible" users (Connolly 2004). Despite this, it wasn't long before accidental poisonings of humans (Williams 1948) and domestic animals (Nichols *et al.* 1949) were reported.

THE TASMANIAN SITUATION

Rabbits in higher rainfall areas have better survival of young in dry years (Williams *et al.* 1995) so it is not surprising that in Tasmania in the late 1940s rabbits were in high numbers following a dry period (fig. 1). Both Oatlands, in the central wool-growing area of the state, and Wilmot in the higher rainfall northwest, as well as other areas, were suffering from significant rabbit problems at the time.

The poisons then used, strychnine and phosphorus (as a phosphorus–pollard mix), killed only 60–70% of rabbits leaving adequate numbers for the next breeding season. There also was a shortage of fumigants for destroying rabbits in burrows, further limiting control options (memo from A.E. Hughes, Senior Stock Inspector to G.K. Meldrum, Acting Chief Veterinary Officer, May 1949, TGAM).

At this time rabbit control was carried out under the provisions of *The Rabbit Destruction Act 1889*, under which the power to enforce rabbit destruction was vested in local government. Councils were able to raise rates and employ inspectors for the purpose of implementing the Act. The Department of Agriculture had the authority to assume a council's responsibility for rabbit control if, in the opinion of the head of the Department, a council was not complying adequately with the legislation. In practice the Department of Agriculture did not have staff to assume this role and even in the case of councils which did not control rabbits it was not possible for the Department of Agriculture to take effective action. Given the high rabbit numbers in the state in 1949 the Act was seen to have

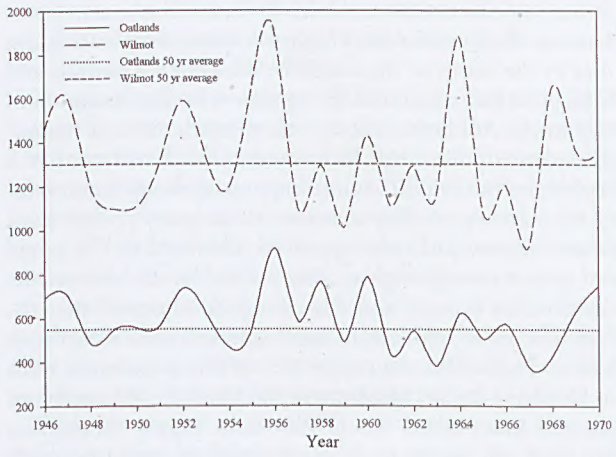

FIG. 1 – Rainfall at two sites in Tasmania, 1946–70 (data from Barnes-Keoghan 2002).

failed in its aim and Parliament initiated a review of the functions of the rabbit control authorities (Meldrum 1959). A new Act, *The Vermin Destruction Act 1950,* transferred power over rabbit control from local government to the Secretary for Agriculture. It also widened the definition of a landholder to include public instrumentalities and the Crown, and rabbit control on any leased land, whether Government or privately owned, became the responsibility of the lessee. In addition, the Secretary of Agriculture could order departmental staff to carry out rabbit control at the owner's expense if the owner did not comply with the orders given by a rabbit inspector.

With the passing of *The Vermin Destruction Act* the Department of Agriculture established a Vermin Control Section of 16 district inspectors and three mobile teams of two men, all under the control of a Senior Vermin Officer (Alan Hughes). The detailed administrative control was carried out by the Chief Veterinary Officer, Keith Meldrum (Meldrum 1959). The mobile teams were equipped with a Land Rover and caravan and, if required, a tractor. The majority of their work was in response to requests for assistance with routine rabbit control, but they also spent considerable time working on land owned by government agencies (Hughes 1959). They camped where they were working, sometimes for weeks at a time (D. Brooks *pers. comm.*), and the landowner was charged for the cost of labour and materials used by them.

The search for improved techniques was started in May 1949 when Alan Hughes wrote to Keith Meldrum suggesting there was scope for improvement of destruction methods and asking him to request the CSIR to conduct research on poisons and methods of poisoning rabbits, and particularly for information on strychnine poisons that could be laid with a poison cart (TGAM). The concept of a new poison may well have been stimulated by a report of a talk to the Victorian Chamber of Agriculture by Francis Ratcliffe, leader of the CSIR Wildlife Survey Section (*Advocate* 28 February 1949). He suggested that poisons developed during the war were likely to be better than those then being used but it was first necessary to learn more about the rabbit, and satisfactory poisoning measures would be applied eventually. Ratcliffe's comments on poisoning came at a time when myxomatosis trials carried out in his section were having very poor results with the disease not spreading and appearing to be a failure (Rolls 1969).

In June 1949 Keith Meldrum wrote to ICI in Sydney asking for information on the rodent poison sodium monofluoroacetate about which he had read in recent years. Later in the month Alan Hughes wrote again pointing out that in the north of the state, the demand for poisons and fumigants had exhausted all supplies with the exception of strychnine. As Eberhard & Co., the manufacturers of "Gisko" phosphorus poison bait in Launceston, still had not had a reply from the Prices Commissioner to their application for an increase in price they were not releasing any poison. Even when the new price was approved, Eberhard & Co. could not source enough high-quality pollard locally to meet the demand for poison, and Alan Hughes requested that the Department of Agriculture make representation to Gibson's Mill in Hobart for the supply of one ton of pollard a week to Eberhard & Co. Meldrum replied that the Wheat Board claimed that pollard was in very short supply throughout the state and therefore no extra allocation could be made from Hobart (TGAM).

In early August 1950 Meldrum, then the Chief Veterinary Officer, sent a memo to Hughes to say that he had received a reply from ICI and they had obtained information on Compound 1080 for him from the CSIR. He saw the problems being the toxicity to humans and domestic animals and the prohibitive cost, with a recent purchase by the Director of Health in Canberra being £6/7/- per pound with one ounce being sufficient to make only 28 pounds of bait. Also, the Commonwealth would only allow its importation and use by departmental officers whose function was solely the destruction of vermin. This restriction would change poisoning practices, because strychnine and phosphorus were freely available and farmers could carry out rabbit control with no government involvement. He ended by recommending against experiments at that time. The argument did not seem to convince Hughes, as within a week he replied pointing out that strychnine was also highly poisonous and the odourless, tasteless nature of 1080, while being a danger if made available to all and sundry, was one of its appeals. The bitterness of strychnine was one of the reasons rabbits often refused to take poisoned bait. Regarding to the cost, the price of 1080 was approximately 8/- per oz while strychnine was 14/- per oz and 14/- worth of 1080 would be sufficient to poison 49 lbs of pollard or apples but one oz of strychnine would be sufficient to poison only 40 lbs. In addition, a farmer near Launceston had offered to allow a trial on his property if 1080 could be obtained (TGAM).

On 21 August 1950 Meldrum sent two memos to Hughes, the first to say that he was applying to the Director, Veterinary Hygiene in Canberra for permission to import 1080 for trial purposes, and suggesting that thallium sulphate be also trialled at various strengths. This had been used by the Chief Inspector of Health to kill rabbits in the Rokeby area near Hobart with an excellent kill recorded. The second memo reported on a U.S. Fish and Wildlife Technical Advice relating to the use of coloured baits to repel birds. This report presumably was based on the paper published by Kalmbach & Welch (1943), and indicated that Keith Meldrum was already considering the possibility of protecting birds from being poisoned (TGAM).

No objection to the import of 2 lbs of 1080 was raised by the Commonwealth Director General of Health, leaving the way open to carry out trial work in Tasmania. An approach to ICI in Hobart, as Monsanto agents, to purchase the 1080 resulted in a requirement for the Department of Agriculture to acknowledge in writing that it realised the toxicity of this material, understood the risks involved and had read pamphlets supplied by the company. This reflected the earlier agreement between the US Government and Monsanto (TGAM).

Meldrum wrote to Francis Ratcliffe of the CSIR in November 1950 to say that the Department of Agriculture had sought approval to import 1080, was also interested in thallium sulphate and asked for any information on other poisons, decoys (lures) or baits. In reply, Ratcliffe noted that the CSIR was trialling new poisons and that 1080 was promising as it was well accepted by rabbits and was effective. He thought thallium sulphate was not likely to be of much use due to its low toxicity and high cost and ended by suggesting that it would be a good idea to plan their research programs together when he had a man in place in the team whose special job would be the field investigation of poisons (TGAM).

The 1080 finally arrived in November 1951 and Keith Meldrum arranged to procure 20 rabbits to allow the

determination of the minimum lethal dose, the amount needed to kill all of a group of animals (LD_{100}). This test resulted in a calculated value of approximately 1 mg/kg body weight, compared with a value of approximately 0.8 mg/kg later published by Lazarus (1956) based on the work referred to by Ratcliffe (TGAM).

In early February 1952 a series of trials was initiated to field test 1080 bait, with Jeff Bignell, a Department of Agriculture veterinary officer, in charge. The first trial in a netted paddock at Bothwell was to test a range of baits, so apples, pollard and jam, pollard and sugar and pollard and dehydrated apple waste were used as free feed. Apples were used on two miles (3.2 km) of the furrow and the remaining baits were equally spread over another mile. Apples were taken in preference to any other bait and as a result, the area which had been free-fed with apple was poisoned with apple containing approximately 0.1% 1080 from powder. The results were initially disappointing with only 5–10% of the bait taken and few rabbits found dead. A thorough search of the area, however, resulted in 216 rabbit carcasses being picked up and after excavating a few burrows it was evident that many more had died. About 40 more carcasses were found in the following fortnight as rabbits ate the remaining bait.

The second trial, also at Bothwell, was to determine the effectiveness of 1080 in a pollard mix similar to that used in a poison cart, a trailer used to lay baits automatically. Pollard and jam was compared with pollard, sugar and dehydrated apple waste (10:1:1) at a range of 1080 concentrations. The bait was laid in a 5-mile (8-km) long furrow around a crop and was a failure with little bait taken, but no free feeding appeared to have been carried out prior to the poisoning. A subsequent strychnine poisoning and trapping on the same furrow yielded 4000 rabbit carcasses.

In the third trial, near Ouse, 1080 was first mixed into a solution and then applied to bait at concentrations of 1 oz of 1080 to 28, 56, 112, 168 and 224 lb carrot (0.22, 0.11, 0.056, 0.037 and 0.028% 1080). This was to test carrot instead of the traditional apple bait and to see whether bait shyness occurred at the higher concentrations. All concentrations were taken well and the "result left nothing to be desired and the owner's satisfaction in the kill was matched only by his chagrin at being unable to obtain 10 lbs of 1080" (J. Bignell internal file report, April 1952, TGAM).

As the previous trials had been carried out in dry conditions, traditionally the best time for rabbit poisoning because there is little alternative feed available, the fourth 1080 trial was carried out in the highlands in April in an area with green feed. Free feeding had been carried out inadequately, and as a consequence rabbits were not well attracted to the bait. Although at least 90% of the 4 cwt (200 kg) of apple bait with a 1080 concentration of 1 oz/cwt (0.056%) was eaten, the percentage kill did not appear to be very good.

The area chosen for the next trial had difficult conditions for rabbit control. A deep gorge ran through the 2000-acre (800-ha) block, and the whole area had been poisoned twice with phosphorus and once with strychnine, the latter only eight days before the 1080 baiting when 630 dead rabbits were collected. Apple bait was used at 1 oz/160 lb apple (0.039%). More than ¾ ton (870 kg) of bait was used and 1500 rabbits were picked up with many more crow–picked carcasses left to decay. The local rabbit inspector accompanied by his dog saw only four live rabbits during a subsequent inspection (TGAM).

The final in this group of trials was in May 1952 to compare apple bait with boiled oats. Initially apples were taken better, but following rain the oats became more palatable. This trial used the, by then, standard 1080 concentration of 0.039%. Before the final trial Keith Meldrum, among others, must have been convinced of the effectiveness of 1080 because in early May 1952 he contacted Monsanto Chemicals in Victoria for a quote on 100 lbs of 1080 to be used in the following 12 months. By the end of May Alan Hughes reported that farmers were applying to have the Department lay 1080 on their properties. On 25 June the Secretary for Agriculture asked the Supply and Tender Department to order 200 lbs of 1080, with 15 lbs being airfreighted for use in the current season. A firm order was placed with Monsanto at the end of July, but the Commonwealth Customs would issue an import permit for only 15 lbs as the remainder was thought to be in excess of Tasmania's normal needs. Keith Meldrum, via the Secretary for Agriculture and the Manager of the Supply and Tender Department questioned the Customs department's ability to assess the need for 1080, a new poison, and pointed out that the 200 lbs would be 12 months' supply. Customs was not convinced by the argument and it was only when the Tasmanian Minister for Agriculture and Senator Wordsworth raised the issue with the Commonwealth Minister for Trade and Customs that the permit was issued in January 1953. The airfreighted 15 lbs arrived in February to allow poisoning to begin in earnest, although a small amount had been borrowed from the CSIRO in the meantime to allow work to continue (TGAM).

Once the Department had decided on 1080 for rabbit control, Keith Meldrum wrote to the Chairman of the Pharmacy Board (10 July 1952) suggesting that some control over its use be implemented because of its toxicity, solubility and lack of taste, colour or antidote. The Pharmacy Board, however, considered that as agricultural and horticultural bodies were exempt from the Poisons Act, the use of 1080 should be controlled by the Stock Medicines Board and as Monsanto would only sell to Government agencies, there was sufficient control already (TGAM).

In July Francis Ratcliffe wrote to Meldrum to say that their results with carrot bait had been similar to the Tasmanian experience and it was probably the best bait to use with 1080. In the same month Alan Hughes began to train the Vermin Destruction Team in 1080 poisoning techniques (TGAM).

In September 1952 interest was expressed in 1080 trial results by the New Zealand Department of Agriculture which had not previously encouraged its use because of the risks to livestock (TGAM).

Francis Ratcliffe wrote to Meldrum in February 1953 suggesting that because his section and the Tasmanian Department of Agriculture were both conducting 1080 trials, they should have a policy for 1080 use which should be strictly adhered to by anyone using the material. In his reply, Meldrum reinforced the fact that 1080 would be sent out to field officers as a liquid for incorporation into bait and would probably be coloured blue, a practice finally implemented over 30 years later (Statham 1987), although either fluorescein (yellow/green) or nigrosin (black) were used to colour the 1080 in the intervening period (TGAM).

With the arrival of the 1080 another training day was held near Ross in February 1953 to ensure the field staff were fully conversant with its use. This training day was also attended by Ian Rowley, a CSIRO scientist who had

just started working in Tasmania on rabbit behaviour and baiting techniques, an area of research Ratcliffe had seen as necessary in 1949. Charges for labour and materials were set and a circular for landholders wanting to apply for 1080 use on their property produced and circulated (TGAM). The field poisoning techniques used were those described by Meldrum *et al.* (1957).

There were excellent results with rabbit control. For example, in April 1953 a letter from a farmer near Penguin to the Devonport Vermin Officer stated "I have done a considerable amount of poisoning with strychnine with apples and swedes in the past. Although good kills have been obtained the rabbit population has not been reduced to such an extent as to be visible to the eye. However after using 1080 the visible decrease in rabbits is outstandingly obvious. Where 50 rabbits were visible round a warren not one is now seen. A fortnight after poisoning I walked over the property to see its effect and saw only two rabbits where hundreds were sighted previously".

It was not long before problems began to occur, with 33 sheep being poisoned in March 1953 when an area was restocked four days after poisoning. An inspection revealed the uneaten bait had not been well covered and there was little other feed available. Problems with non-target kills continued, and in June 1953 Keith Meldrum requested all vermin officers to provide information on the non-target kills in their areas (TGAM). The recorded deaths in domestic animals (table 1) indicate that landholders were probably treating 1080 as they had strychnine in relation to removal of uneaten bait. Strychnine has a toxic dose for sheep of 8 mg/kg (Hone & Mulligan 1982) compared with 0.4 mg/kg for 1080 (Annison *et al.* 1960, Hone & Mulligan 1982) and it was therefore more important to remove or bury residual poisoned 1080 baits.

TABLE 1
Non-target kills reported March–June 1953

Horses	1
Cattle	9
Pigs	1
Sheep	490
Dogs	31
Cats	26
Deer	6
Kangaroos	100+*
Possum	47
Bandicoot	20+
Starlings	large nos
Black birds	large nos
Parrots, crows, wren, plover, fantail	few of each

* Primarily in the Royal George area

There are no data available on the non-target effects of strychnine or phosphorus because Government inspectors were not involved in its use and there was no requirement for anyone to keep records. It would be expected that the non-target effects of the earlier poisons would be greater because the range in LD_{50} values for different animal groups is lower than 1080 (table 2) hence more would be at risk of poisoning if they ate the bait. In particular, the low LD_{50} for birds would indicate that they would at risk of being killed by apple-based strychnine baits.

The term LD_{50} refers to the lowest dose that should be expected to kill 50% of the animals that received it (Weil 1952). It is a statistical value used to compare the effect of a chemical on different species or different chemicals on the same species, compared to the minimum lethal dose (LD_{100}) which is the amount needed to kill all of a group of animals.

By the beginning of July more than 100 of the 200 lbs of 1080 had been used and Keith Meldrum warned the Secretary that they would need another 100 lbs by February 1954, resulting in an order for 200 lbs being placed with Monsanto (TGAM).

In order to find accurate figures for the effectiveness of 1080 two trials were conducted inside netted paddocks. These trials and the results are described in Meldrum *et al.* (1957). Essentially the first trial resulted in 88% of breeding does being killed but many 3–5 week-old young survived, while in the second, in a non-breeding period, there was over 95% mortality. This reinforced the ideas that 1080 was superior to strychnine and phosphorus (TGAM).

In the first half of 1954 there was interest from other jurisdictions in the results of 1080 poisoning in Tasmania, including requests for information on 1080 rabbit poisoning from the Ministry of Agriculture and Fisheries in the United Kingdom; Vermin and Noxious Weed Branch, Department of Crown Lands Victoria; and the Director of Agriculture in New South Wales. Victoria and Western Australia had already begun rabbit control trials with 1080, but the Chief Vermin Control Officer from Western Australia, A.R. Tomlinson, wrote asking for information on the practical arrangements for rabbit control with 1080 including charging, costs and the effectiveness of the Tasmanian staffing procedures. Western Australia set up a mobile team system in 1955 which was similar in most respects to the Tasmanian system (Tomlinson *et al.* 1956). The Secretary of the New Zealand Rabbit Destruction Council also requested that two staff

TABLE 2
LD_{50} (mg/kg body wt) of strychnine, phosphorus and 1080 in different animals

	Species	Strychnine	Phosphorus	1080
Introduced carnivore	Dog	0.75	3 – 6	0.07
Introduced omnivore	Pig	0.5 – 1	1 – 6	<1
Introduced herbivore	Rabbit	0.6	4	0.4
Native herbivore	Tas. pademelon	No data	No data	0.13
Native carnivore	Tas. devil	No data	No data	4.24
Bird	Wedge tailed eagle	No data	No data	9.49
Bird	Mallard duck	2.9	No data	5.6 – 8.6
Amphibian	Bull frog	2.2	No data	54

Data from Hone & Mulligan 1982, McIlroy 1981, McIlroy 1982, McIlroy 1984.

be allowed to visit Tasmania to study the work on 1080. I. Carney, a veterinary officer and A. Forrester, a Principal Rabbit Inspector, arrived in late October for a 10-day visit (TGAM).

During this period there was a number of letters to the editors of the local papers complaining about the effects of this new poison on native wildlife, deer and dogs. Interest in the issue seemed to wane when Dr Eric Guiler from the University of Tasmania was reported in June as having told a meeting of the Animals and Birds Protection Board that it was not as great a threat to native animals as snares used for rabbit trapping or strychnine. "A smear campaign had been conducted against use of this poison", he said, "and incredible stories of its effectiveness were being circulated" (*Mercury* 23 June 1954).

The new order for 1080 from Monsanto ran into trouble in July 1954 when the Department of Trade and Customs refused to allow the import from America. Another company, Associated Fumigators in London, was reported to be producing 1080 and under the United Kingdom and Australia Trade Agreement 1932, goods had to be sourced in Britain if possible. Enquiries to Associated Fumigators revealed that it produced sodium fluoroacetate and also another named fluoracetamide, 5 lbs of which was ordered in August for trials. Fluoracetamide had been shown to be highly toxic in early British work (McCombie & Saunders 1946), and had been given the code 1081 in the USA. In Tasmania, however, it was called 1066. This material was claimed by Associated Fumigators to be more acceptable to rodents and cheaper to produce than 1080. An enquiry to Francis Ratcliffe revealed that he knew about fluoracetamide, had been considering getting some for trials but was delighted to leave the preliminary trials to Keith Meldrum and his colleagues (TGAM).

Towards the end of 1954 there were differences between the states in their attitude to 1080. Tasmania, Western Australia and Victoria had carried out trials and were providing a service to landholders. New South Wales had carried out a trial at Trangie and in a memo to all veterinary officers and Inspectors of Stock the Chief of the Animal Industry Division commented that it would be unlikely to be introduced to NSW. The reasons were the trial had shown 1080 was no better than strychnine and the author speculated that 1080 use would be likely to result in the loss of a great deal of wildlife. The Department of Health also objected because of the serious effect it could have on humans. In Queensland, according to the United Graziers Association, who wanted to use 1080 for dingo control, the Director-General of Health refused to release the material under any circumstances. The South Australian Department of Health was discussing allowing the use because they had applications for permits which were necessary under their legislation and requested information on the results in Tasmania. Keith Meldrum replied to the NSW memo with the Tasmanian experience which negated the claims. He also, supplied SA with the information they wanted, as he had with any group or individual who requested information (TGAM).

Victoria went further and in September introduced a regulation under the Health Act setting conditions for 1080 bait preparation and use, but also allowing the sale of 1080 powder (Sodium fluoroacetate (Compound 1080) Regulations 1954). Alan Hughes raised the question of this 1080 reaching Tasmania and Keith Meldrum asked for more information from Victoria, particularly as to how they could get around the Monsanto requirement for it to be used by government agencies only. The answer was that Victoria was supplied with 1080 by Associated Fumigators which had no such restriction. In addition, the Superintendent of the Vermin and Noxious Weeds Branch replied that its inspectors were supplying poisoned bait to landholders, a practice not used in Tasmania, but that he hoped that in one or two years landholders would obtain supplies of 1080 directly without going through their department.

Meldrum suggested to the Pharmacy Board that they might like to reconsider their ideas on declaring 1080 a poison as it would soon be freely available in Victoria and could make its way to Tasmania. In January 1955 the Board did reconsider and agree to include 1080 as a poison and Meldrum then suggested that fluoracetamide should also be included as both were potentially available. In February Alan Hughes reported rumours of 1080 powder being imported to Tasmania, and this was passed to the Pharmacy Board by Keith Meldrum, but it was not until August 1956 that the two compounds were included in the new Poisons Schedule to provide some control over their sale and to prevent illegal importation of 1080 from Victoria (TGAM).

In March 1955, 2 of the 5 lbs of fluoracetamide were delivered and again Jeff Bignell was given the job of trialling it. In May and June he showed that the minimum lethal dose for rabbits was similar to 1080 and there was no difference in acceptability. He also found that 1 oz to 25 lbs (0.25%) of wheat was effective on native hens, *Gallinula mortierii,* a pest in young crops, but suggested it would be too dangerous to adopt on a large scale for that use (J. Bignell internal memorandum to J. Green, Deputy Chief Veterinary Officer, 28 June 1955, TGAM). In a trial in August with 1080 and 1066 compared in alternate half-mile (800-m) strips over a 13-mile (21-km) poison furrow he found that more 1066 was taken by rabbits and attributed it to the slower action allowing greater intake. Bignell considered that the slower action more than compensated for the increased poison needed. In reporting the results to Francis Ratcliffe, Meldrum suggested that fluoracetamide could replace 1080 as its slower action could minimise bait shyness. It was not, however, adopted and no more appears to have been purchased (TGAM).

In September 1955 interstate problems again arose when Pesticides Ltd in South Australia began selling 1080 oat bait with 1oz of 1080 per 125 lbs of oats (0.05%) and had agreement with several Tasmanian retailers to stock it. This oat bait was on sale in the state until a change to the *Poisons Act* in 1959 tightened the controls on both 1080 and fluoracetamide.

The final significant event occurred when Alan Hughes was invited to conduct training schools for New South Wales Pastures Protection Board officers in early 1959. The Department of Agriculture in that state was planning a statewide rabbit control campaign in the autumn of 1959 using 1080. This was delayed by the inspectors being involved in control of a locust plague, but Hughes finally spent three weeks in NSW in June (TGAM).

From that time there were few significant changes to rabbit control practices in Tasmania. The early 1960s saw a big increase in rabbit numbers, during the low rainfall years (fig. 1) and by 1964 there were 25 Department of Agriculture staff, 17 Forestry Department staff and one Lands and Survey officer trained and authorised to hold stocks of 1080 solution to be used for rabbit control using the techniques developed in early trials (TGAM).

The Tasmanian rabbit control scheme based on the use of 1080 was developed essentially by two people and had influences on practices in several other states. Francis Ratcliffe summarised the situation well when he wrote in a letter to Keith Meldrum in 1957: "your scheme hinged very heavily on the personality of one or two people (notably Alan and yourself) and if, in the course of events, less satisfactory key personnel had to be substituted, the efficiency of the machine would suffer".

Following this period a few changes in the use of 1080 occurred. They included the reduction in concentration of 1080 on bait, first from 0.038 to 0.02% based on the research of Ian Rowley (Rowley 1960) and later to the current 0.014% and the complete replacement of apple with carrot as bait to reduce the attractiveness to birds.

The reduction in rabbit numbers as a result of poisoning and myxomatosis led to greater investment in pasture development and a subsequent increase in populations of wallaby and possums (A. Morrison, *pers. comm.* to H. Statham). Deliberate, rather than accidental, poisoning of wallabies was certainly being carried out by 1956, when 49 landholders on Flinders Island were given permits by the Animal and Plant Protection Board to poison wallabies and kangaroos. Later, control of these species in agricultural and forest areas with 1080 has led to much of the public concern about its use and contributed to the change from its ready acceptance in the 1950s to the current plan to phase it out.

Probably the most prophetic comment about 1080 use was made in an internal US Government report by one of the early researchers on control of coyotes when he wrote about 1080: 'It does not at present have thallium's bad name, but if not properly handled 1080 might acquire a reputation fully as bad if not worse" (Robinson 1945, cited by Connolly 2004).

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TABLE CAPE VENT XENOLITH SUITE, NORTHWEST TASMANIA: MINERALOGY AND IMPLICATIONS FOR CRUST-MANTLE LITHOLOGY AND MIOCENE GEOTHERMS IN TASMANIA

by F. L. Sutherland, L. R. Raynor and R. E. Pogson

(with one plate, two text-figures and eight tables)

Sutherland, F. L., Raynor, L. R. & Pogson, R. E. 2005 (16:xii): Table Cape vent xenolith suite, northwest Tasmania: Mineralogy and implications for crust-mantle lithology and Miocene geotherms in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 139: 7–22. ISSN 0080–4703. Mineralogy & Petrology, Australian Museum, 6 College Street, Sydney, New South Wales 2010 Australia (FLS*, REP); deceased (LRR). *Author for correspondence.

The Miocene Table Cape vent erupted a diverse mantle-crust xenolith suite within its fractionated nephelinitic matrix. Assemblages include mantle metaperidotites, garnet-metawebsterites and rarer garnet-metaclinopyroxenites, garnet-metawehrlites, metawebsterites and crustal two-pyroxene granulites. Most metapyroxenites and granulites represent the Ti-Al-bearing augite suite and their bulk geochemistry indicates transitional olivine basalt magmatic affinities. Metasomatised, hydrous lithologies are only rarely present. Co-existing pyroxenes in the xenoliths provide re-equilibration temperature estimates from 860–1075°C (for the whole suite) and temperature-pressure estimates for the garnet metawebsterites from 1055–1070°C and 1.2–1.4 GPa. This gives a Miocene mantle geotherm gradient at least 80–130°C higher than the Southeast Australian (SEA) western Victorian geotherms. However, considerations of Moho depths from new seismic surveys below Table Cape (~32 km) suggest that the indicated geotherm is more strongly perturbed in its lower levels than at the mantle-crust transition. This localised perturbation is attributed to adjacent magma chamber activity in the mantle (Boat Harbour basalts) just prior to Table Cape vent activity. Tasmanian Miocene geotherms (Table Cape, Bow Hill) achieve relatively high gradients and reinforce suggestions of local variation in East Australian geothermal gradients. They illustrate the potential complexities in comparing xenolith-derived geotherms from different areas in general, both from thermometer/barometer selection and from associated magmatic heat inputs.
Key Words: Table Cape volcano, Cenozoic, xenoliths, mineralogy, mantle, crust, thermobarometry, geotherms, magma chamber.

INTRODUCTION

Table Cape is a prominent bluff of coarse-grained alkali dolerite (although previously mapped as crinanite, the preferred specific nomenclature is now teschenite; see Le Maitre 1989). It forms a massive core of a substantially eroded volcanic centre (fig. 1). The teschenite fronts on to Bass Strait in cliffs up to 179 m a.s.l. (Wynyard 1:25 000 Sheet; 55GCQ930655, AGC66, Everard 2003). This slightly differentiated body only becomes more distinctly alkaline in its chemistry in late-stage pegmatoidal veins (schlieren) and it incorporates ultramafic xenoliths and xenocrysts of mantle origin, particularly in its lower levels (Gee 1971, Piestrzeniewicz 1972, Everard 2001). Lavas from the Table Cape centre form a remnant apron, in parts deeply weathered, that was dated at 13.3 ± 0.2 Ma at Tollymore Road quarry (Sutherland & Wellman 1986). The lavas overlie a range of older lithologies (fig. 1) and extend west of Table Cape to Jacobs Boat Harbour as a mappable unit of normal magnetic polarity (Sutherland *et al.* 2004, fig. 12).

Vent pyroclastic deposits up to 5 m thick outcrop on the south shore of Table Cape (55GCQ930648, AGD66). Here they underlie a north-dipping base to the teschenite and contain a range of mantle and lower crustal fragments within a basaltic and comminuted country rock matrix (Sutherland *et al.* 1989, Everard 2001, Sutherland *et al.* 2004, figs 8d-f, 10f). Rare fragments of Lower Miocene marine sediments in the pyroclastic beds indicate an age younger than the marine beds. The pyroclastics include irregular sill-like bodies of chilled tachylytic basalt that form a more resistant protection to the included fragments. The deeper origin xenoliths are important in reconstructing the underlying Tasmanian lithosphere and its geothermal state at the time of volcanism, as they not only include garnet-two pyroxene assemblages suitable for geothermobarometry but also diverse mantle peridotites and pyroxenites (Sutherland *et al.* 1994, 2004, Beyer 1998, Beyer *et al.* 2001). The Table Cape suite is one of only two known garnetiferous mantle xenolith sites in Tasmania, the other being at Bow Hill, west of Oatlands in the central midlands (fig. 1).

This study presents a more complete account of the Table Cape vent xenolith mineralogy and uses new thermobarometric methods to discuss their context within recent studies on the Southeast Australian lithosphere in the Cenozoic and its geothermal relationships (Graham *et al.* 2003, Sutherland *et al.* 2004, Roach 2004). The paper integrates the Table Cape vent xenolith data with Boat Harbour (Sutherland *et al.* 1996) and provides a revised lithospheric framework for the Wynyard-Boat Harbour region. The proposed lithology is then correlated with new seismic data on crust-mantle structures under northern Tasmania (Rawlinson *et al.* 2001, 2004).

SAMPLES AND ANALYTICAL METHODS

The Table Cape vent rocks contain numerous xenolithic and xenocrystic fragments. The fragments of mantle-lower crust origin include common spinel-metaperidotites up to 10 cm, sparse garnet-metapyroxenites and granulites up to 8 cm, rarer pyroxenites up to 6 cm and sporadic pyroxene and spinel megacrysts up to 3 cm across, as summarised in Everard (2001).

The samples for this mineralogical study were collected by breaking up the dense glassy basalt, which provided more protected, fresher samples than those found in weathered

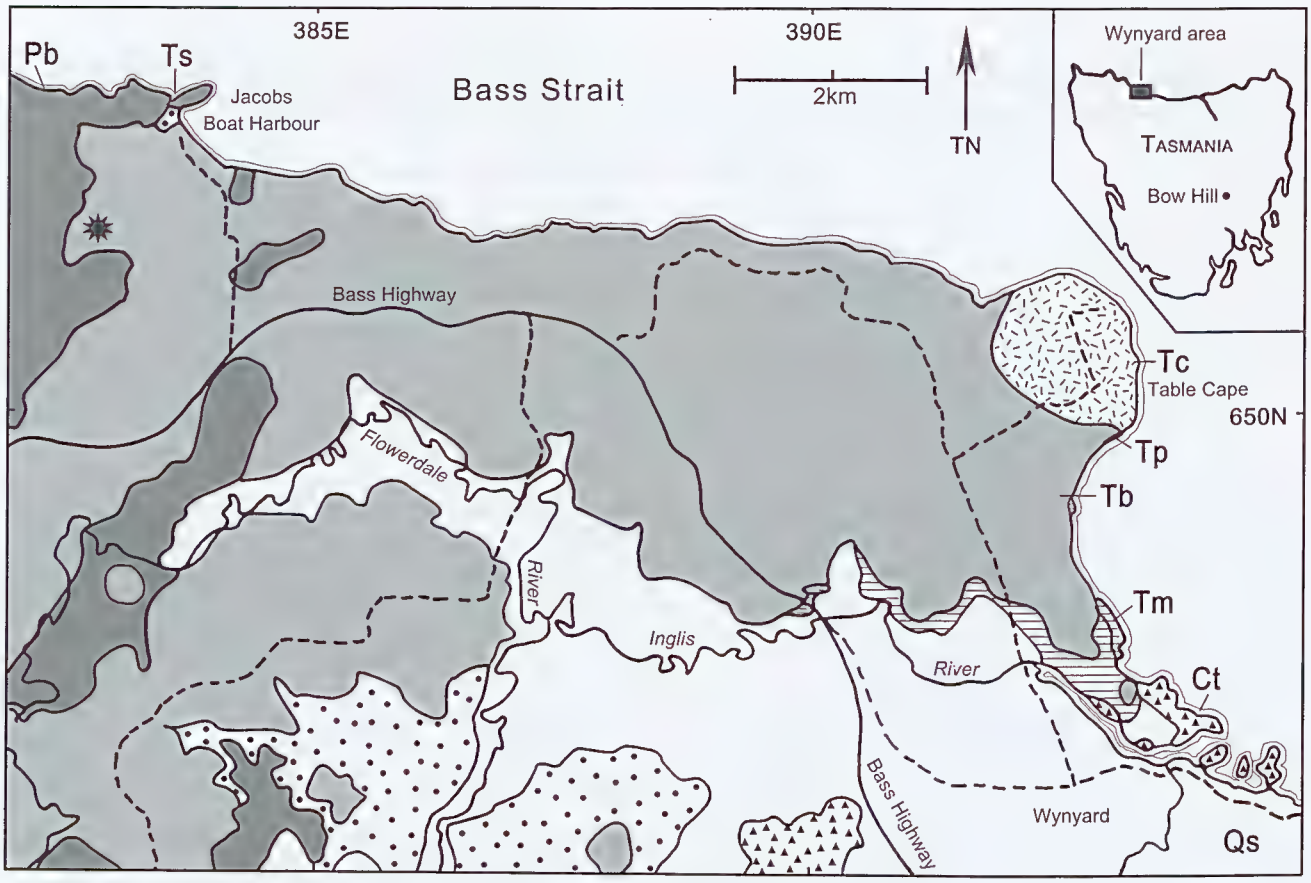


FIG. 1 — Geological map of the Table Cape–Jacobs Boat Harbour area, west of Wynyard, with Table Cape intrusive core (Tc), Table Cape vent pyroclastics (Tp), Table Cape basalt flows (Tb), underlying Miocene marine beds (Tm) and Carboniferous glacial beds (Ct). Basalt (grey areas) include flows from the Cassidys Creek centre (star) in the western part and overlie Tertiary sands and gravels (Ts) and Precambrian basement beds (Pb). The drainage includes the Flowerdale River (west) which joins the Inglis River with the outlet near Wynyard Creek (east) at Wynyard. The blank land areas include Quaternary alluvium and coastal sands (Qs). Geology after Gee (1971), Sutherland et al. *(1996) and Everard (2003).*

pyroclastic matrix. Because of the incomplete recovery of xenoliths by this means, a detailed census of xenolith types was not attempted. A range of inclusions was selected for cutting and polishing into discs ready for petrographic microscope examination and analysis by electron microprobe (EMP). The study material is held in the collections of the Australian Museum. The host tachylyte was analysed from hand-picked fragments to avoid included material as much as possible, before crushing for analysis for major, minor and trace elements using conventional X-ray fluorescence (XRF) techniques (table 1).

The examination of polished samples by a Leica DMLP polarising microscope with DC 300 digital camera attachment identified a number of xenocryst and xenolith assemblages for detailed analysis and photography (pl. 1). These included:

(a) Pyroxene megacrysts (table 2); clinopyroxene, orthopyroxene.

(b) Metaperidotites (table 3); spinel-metalherzolite, spinel-metaharzburgite.

(c) Metapyroxenites (table 4); metawebsterite, mica-metawebsterite.

(d) Garnet-metapyroxenites (table 5); garnet (± spinel)-metawebsterite.

(e) Garnet-metaclinopyroxenites (table 6); garnet-spinel-metawehrlite, garnet-metaclinopyroxenite.

(f) Two-pyroxene granulites (table 7); spinel-granulite, amphibole-mica-granulite.

The assemblages also exhibit secondary breakdown mineral products related to decompression and melt fluid interactions during magmatic transport. These include clinopyroxene, orthopyroxene, spinel and amphibole (table 8) among other phases.

The mineral analyses (tables 2–8) were largely carried out using an ETEC Autoprobe, fitted with three wave-length spectrometers and a LINK EDS system in the Electron Microscope Section, University of Sydney (L. R. Raynor and F. L. Sutherland, analysts). However, some analyses were made on an automated ETEC electron microprobe at Macquarie University, Sydney, for comparative purposes; (B. J. Barron, analyst). Analyses were averaged from multiple spot analyses (up to 10 per grain) for several grains of each mineral phase. The analyses were standardised against natural mineral standards and used 15 kV acceleration voltage, a sample current of 20 nA and Bence-Albee corrections. Precisions were better than ± 1% for element contents above 10 wt% as oxides, ± 5% at 1–10 wt% oxides and ± 10% at below 1 wt% oxides. Agreement between analyses for the two instruments was usually within ± 2% for oxides over 5 wt%, within ± 8% for oxides between 1–4 wt% and within ± 30% for oxides below 1 wt%.

TABLE 1
Chemical analysis of tachylytic host to Table Cape xenolith suite

Major elements (wt%)		Trace elements (ppm)		CIPW norm (anhydrous)	
SiO_2	42.46	Ni	278	Or	13.61
TiO_2	2.32	Cr	360	Ab	3.00
Al_2O_3	12.39	V	135	An	4.41
Fe_2O_3	2.15	Ba	181	Ne	22.11
FeO	10.74	Sr	1295	Di	25.31
MnO	0.20	Rb	14	Ol	20.49
MgO	10.13	Y	24	Mt	3.18
CaO	8.92	Ga	20	Il	4.49
Na_2O	5.08	Zr	318	Ap	3.19
K_2O	2.26	Nb	81	Cc	0.28
P_2O_5	1.32	Pb	23	An mol %	58.1
CO_2	0.12	Zn	156	= 100 An/	
H_2O+	1.59	Cu	61	(An + 1.061 Ab).	
Total	99.68	Th	7	Differentiation Index	
Mg/		U	4	(Or+Ab+Ne)	
$(Mg+Fe^{2+})$%	62.70			38.7	

Analyst F.L. Sutherland, Macquarie University, Laboratories, Sydney.
(Major elements from X-ray fluorescence spectrometry, using fused borate buttons, with Na_2O determined by flame photometry, FeO by dissolution with HF and ammonium metavanadate and titration against ceric sulphate, with CO_2 and H_2O determined separately: Trace elements from X-ray fluorescence using pressed powder pellets using boric acid bases).
CIPW norm calculated at a ratio of $Fe_2O_3/(FeO + Fe_2O_3) = 0.2$

RESULTS

Host Petrology

The host tachylyte consists of a dark, glassy matrix containing small euhedral, partly corroded olivine (ol) crystals (~7%) up to 0.1 mm across (pl. 1A). These phenocrysts lack the anhedral shapes, strain features and reaction margins observed in the incorporated xenocrysts and xenoliths. Analysis of the tachylyte (table 1) corresponds to a mildly fractionated olivine nephelinite (Mg value <63; Ni 278, Cr 360 ppm; Ab < 3%, An mol% 58, D.I. 39) compared to more primitive Tasmanian nephelinites (Sutherland *et al.* 2004). The presence of mantle inclusions, however, indicates a mantle-fractionated melt. Normative ol for the Table Cape nephelinite suggests a fractionated composition for the microphenocrystic olivine, which co-crystallised with minute octahedral inclusions of the ulvospinel-magnetite series.

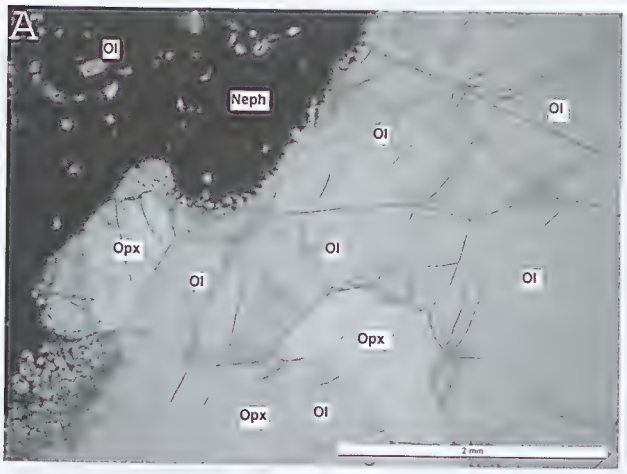
Megacryst Suite

Clinopyroxene (cpx) is the main megacryst within the Table Cape vent (table 2). Unzoned cores are Al-rich augite (En_{52-53} Wo_{35-36} Fs_{11-12}). They show sieved, resorbed reaction rims composed of Ti and Na-enriched augite (En_{44-45} Wo_{40} Fs_{15-16}), which gave low total oxides in EMP analyses due to the inhomogeneous, fluid-bearing melt reactions. A full end-member calculation (Cawthorn & Collerson 1974) shows the cores are notably more Mg-rich (~En_{45} Wo_{24-43} Fs_{9-10} Tsc_{12-13} Jad_{8-9}, Cta_{1-2} Cfs_1) than in most Tasmanian cpx megacrysts (Sutherland *et al.* 2004). The distinctive megacryst chemistry compared to that of clinopyroxenes in the accompanying xenoliths suggests the former represent a high-pressure liquidus phase crystallised from an Mg-rich parental melt. Experimental work on highly undersaturated nephelinitic or basaltic melts suggests such clinopyroxenes can crystallise as liquidus phases from volatile-bearing melts between 1250–1300°C and 2.4–2.6 GPa (Adam 1990).

Orthopyroxene (opx) megacrysts with anhedral, embayed rims and high Mg (~ En_{88} Fs_{11} Wo_1) also occur at Table Cape (table 2). Their compositions, however, closely match those of enstatites in the spinel-metaperidotite xenoliths. Thus, they may derive from these sources rather than from liquidus crystallisation, particularly as opx is commonly reacted out among high pressure liquidus products (Adam 1990). Similarly, the spinel (spl) megacrysts are close to spinel compositions within the xenoliths.

Metaperidotites

Two distinct types were identified. The more common (pl. 1B) is a coarse polygonal-textured assemblage (~75% ol, 15% opx, 5% cpx and 5% spl from visual grid estimates) with strain/extinction in the silicates. The ol (Fo_{89}) and opx (En_{88}) are Mg-rich, the cpx is Al-Na-rich diopside (Wo_{48} En_{46} Fs_6) and the spl is Cr-bearing pleonaste (e.g., Sp_{78} Hc_{12} Cm_8 Mt_1,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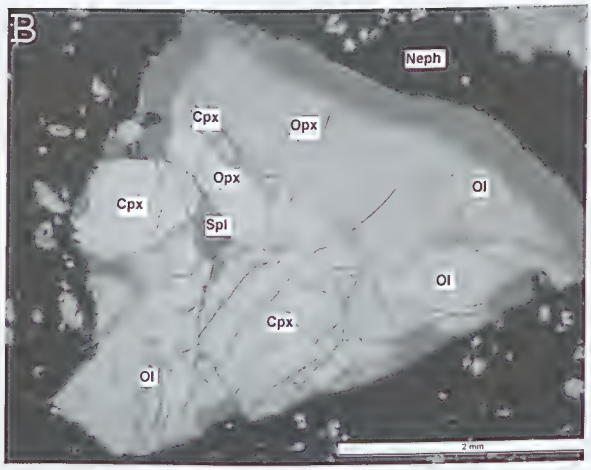
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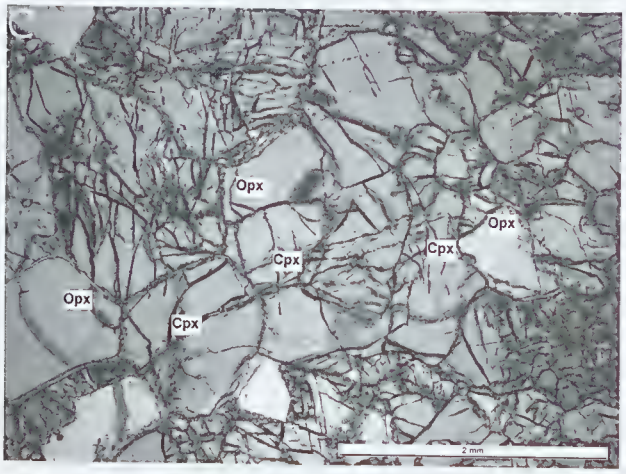
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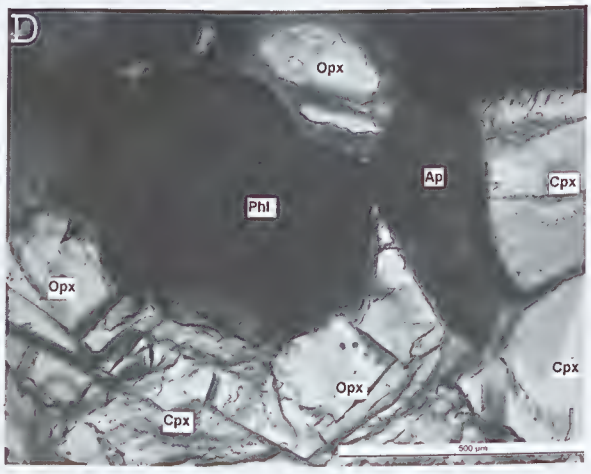
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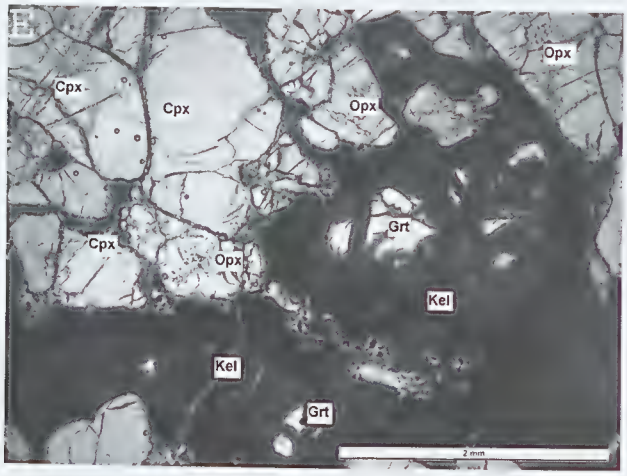
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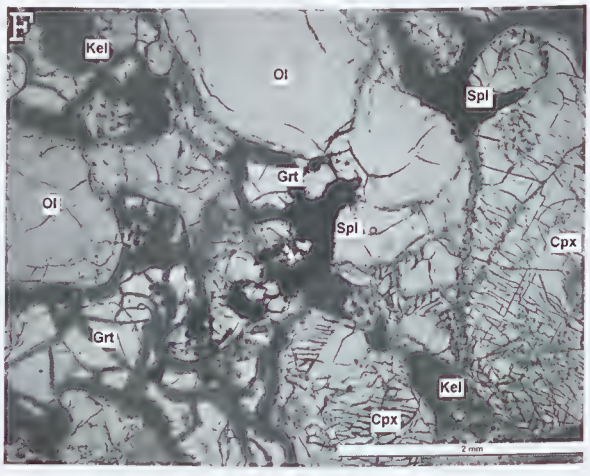
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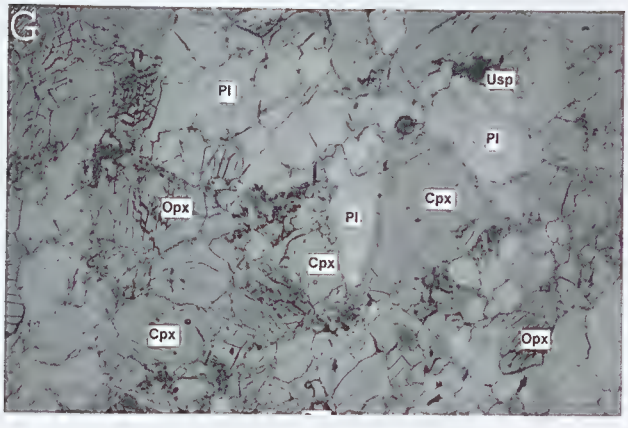
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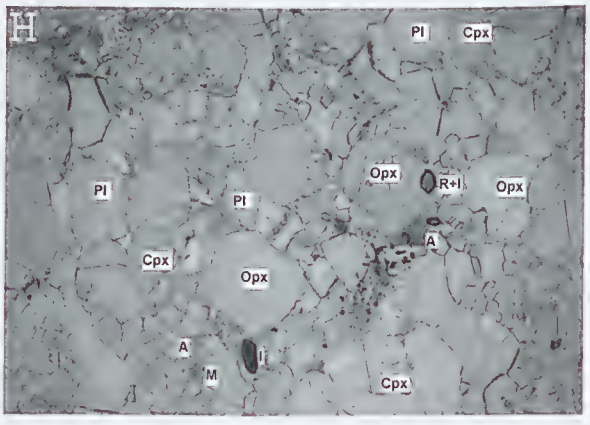
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Usp_1) (table 3). This type dominates mantle xenoliths in the Table Cape region and elsewhere in Tasmania (Piestrzeniewicz 1972, Varne 1977, Sutherland *et al.* 1996).

Rare spinel-metaharzburgite (pl. 1A) exhibits a medium to coarse granular polygonal texture (grains to 5 mm across). It is richer in ol (78.5%) and opx (20%) and impoverished in spl (1%) and cpx (0.5%) compared to the spinel-metalherzolites. The ol (Fo_{91}), opx (En_{89}), cpx (En_{52} Wo_{43} Fs_5) and spl are all Mg-rich phases, with the spl being a Cr-rich magnesiochromite (Mc_{47} Sp_{25} Hc_{22} Mf_5 Usp_1) (table 3). Such highly depleted metaperidotites are rarely described from Tasmanian mantle xenolith suites.

Metawebsterites

Two types of metapyroxenites were found. One lacked obvious accessory phases and consisted of subequal polygonal grains of cpx and opx up to 4 mm across (pl. 1C). Pleochroic cpx (α pale green, β pale brown, γ pale pink) is Al-rich, Na-Ti-bearing augite (En_{48} Wo_{40-41} Fs_{11-12}) and pleochroic opx (α pale grey, β pale yellow, γ pale green) is moderately Al- and Fe-enriched (En_{79-81} Fs_{17-19} Wo_2) (table 4). Exsolution lamellae and blebs of one pyroxene within the other occur in some grains.

The other type is cpx-rich, with large pleochroic cpx grains up to 15 mm across. These enclose and intergrow with opx, mica and cloudy apatite grains up to 1 mm across (pl. 1D). The cpx is Al-Mg-rich, Cr-bearing diopside (Wo_{47} En_{47} Fs_6), the opx is Al-bearing enstatite (En_{88}), and the mica is Ti-rich magnesian phlogopite (table 4). Such pyroxenites with Cr-diopside suite characteristics (Wilshire & Shervais 1975) are rare in Tasmania (Everard 2001) and also within eastern Australia (O'Reilly & Griffin 2000).

Garnet-metawebsterites

These consist of polygonal, amoeboid-like and blebby intergrowths of cpx, opx, garnet (grt) and in some cases spl, in grains up to 6 mm across (pl. 1E). Smaller areas of finer grained recrystallised mosaics can occur within coarse-grained matrix. Assemblages carry up to 25% grt, commonly in relicts within reaction rims and patches but rarely in completely fresh grains. Fresh cores are unzoned pyrope of restricted end-member range (Py_{63-64} Am_{22-23} Gr_{9-10} An_{3-4} Uvo_{0-1} Sp_{0-1}; after Knowles 1987); the pleochroic cpx and opx range from sub-equal to cpx-dominant amounts with only 5% opx and include Al-Ti-Na-rich augite (En_{45-47} Wo_{40-41} Fs_{13-14}) and Al-rich opx (En_{77-78}) (table 5).

Two of the five studied garnet-metawebsterites contain up to 5% spinel as blocky interstitial grains or as cores up to 1.5 mm across within reacted garnet enclosures. The spl is Cr-bearing pleonaste (Sp_{65-72} Hc_{24-25} Mt_{2-6} Cm_{0-3} Usp_{0-2}) (table 5). Some grains resemble Fe-hydroxide altered olivine (5%) in one assemblage, which has pervasive fluid inclusion trails and alterations along grain boundaries. These garnet (± spinel)-two pyroxene assemblages allow TP estimates for the Table Cape vent suite, but are notably more Fe-enriched cpx (FeO total >5wt%) than in most garnet-websterite suites (Sutherland *et al.* 1994).

Garnet-metaclinopyroxenite and Garnet-metawehrlite

A rare garnet-metaclinopyroxenite contains abundant reacted garnet (35%). This includes and is intergrown with rounded, embayed and polygonal cpx (55%) grains up to 4.5 mm across. The reacted areas enclose many secondary spl grains, rimmed by pod-like growths of secondary opx, while alteration prevails along cpx grain boundaries. The grt (Py_{62} An_{23} Gr_{11} An_3 Sp_1) and Al-Na-Ti-rich augite (En_{45} Wo_{41} Fs_{14}) compositions are similar to those in the garnet-metawebsterites and one cpx is mantled by a gedritic amphibole (table 6).

A garnet-metawehrlite contains grt (42.5%), cpx (37.5%), spl (10%), and ol (10%). Poikilitic areas of garnet (to over 12 mm across) enclose grains and polygonal clusters of the other minerals (pl. 1F). The garnet is pyrope (Py_{63-64} Am_{22-23} Gr_{10-11} An_3 Sp_1) in composition. The cpx (up to 4.5 mm across) is Ti-Na-rich augite (En_{46} Wo_{42} Fs_{12}), while blocky to rounded spl grains (up to 1 mm across) with narrow secondary opx fringes are pleonaste (Sp_{69-70} Hc_{22-23} Mt_{5-6} Usp_2 Cm_{0-1}) and ol (Fo_{81}) forms subhedral grains up to 2.5 mm across. Other than olivine, the mineralogy (table 6) closely compares with phases in the garnet (spinel)-metapyroxenites.

Two-pyroxene Granulites

These feldspathic rocks form two types. One is a medium-grained, banded assemblage with conspicuous zones of polygonal plagioclase (55%) interspersed with subequal mosaics of pleochroic opx and cpx, mostly 0.5–2.5 mm across, and sparse interstitial irregular spl grains up to 0.5 mm across (pl. 1G). The zoned plagioclase shows lamellar and pericline twinning and is calcic (An_{58-60}); the cpx is Al-bearing diopside (Wo_{46-47} En_{36} Fs_{17-18}), the opx is Fe-enriched

PLATE 1

Photomicrographs of main Table Cape vent xenoliths. (A) Metaharzburgite, in host olivine nephelinite (top left). (B) Spinel-metalherzolite, in host olivine nephelinite. Note reaction rim on xenolith. (C) Metawebsterite, with mosaic-textured pyroxenes. (D) Mica-apatite-bearing metawebsterite. Note basal phlogopite plate (left), cloudy apatite crystal (right) and fluid inclusion trails in the pyroxenes. (E) Garnet-metawebsterite. Note 'kelyphite' alteration rims around inner cores of garnet. (F) Garnet-spinel-metawehrlite. Note large fresh olivine grains,' kelphytised' rims and veins in garnet grains and interstitial spinel grains. (G) Two-pyroxene granulite. Note polygonal texture in plagioclase and pyroxenes and interstitial accessory ulvospinel. (H) Metasomatised two-pyroxene granulite. Note accessory mica, amphibole and rutile grains mantled with ilmenite. All photomicrographs have equal magnification, except for (D) which is enlarged 4X. Symbol for host nephelinite is Neph and for minerals are Ol (olivine), Opx (orthopyroxene), Cpx (clinopyroxene), Spl (spinel), Usp (ulvospinel), Grt (garnet), Kel ('kelyphite'), Pl (plagioclase), Phl (phlogopite), Ap(apatite), A (amphibole), M (mica), R (rutile), I (ilmenite). Microphotographs were taken in transmitted light, I. T. Graham photographer.

TABLE 2.
Representative analyses of pyroxene megacrysts, Table Cape pyroclastics

	Clinopyroxene		Orthopyroxene
	core	resorbed rim	
SiO_2 wt%	50.70	48.76	54.54
TiO_2	0.61	1.36	0.12
Al_2O_3	8.03	8.49	4.70
Cr_2O_3	0.25	-	0.27
FeO total	6.52	8.26	6.87
MgO	16.61	13.25	32.00
CaO	15.54	16.46	0.64
Na_2O	1.18	1.76	-
Total	99.44	98.34	99.14
Cation	$Mg_{52.8}$	$Mg_{44.7}$	$Mg_{88.1}$
ratio%	$Ca_{35.5}$	$Ca_{39.9}$	$Fe_{10.6}$
	$Fe_{11.6}$	$Fe_{15.5}$	$Ca_{1.3}$

Analyst F. L. Sutherland

TABLE 3
Comparative representative analyses, peridotitic xenoliths (DR 10491)

Mineral/	Olivine		Orthopyroxene		Clinopyroxene		Spinel	
Rock Type	SML	SMH	SML	SMH	SML	SMH	SML	SMH
SiO_2 wt%	40.38	41.05	53.90	55.46	50.99	52.71	0.09	0.09
TiO_2			0.15	0.08	0.74	0.11	0.18	0.12
Al_2O_3		0.09	4.62	2.65	6.94	3.04	60.33	26.80
Cr_2O_3		0.03	0.29	0.77	0.67	1.16	7.69	40.25
FeO total	11.09	8.95	6.89	5.70	3.01	2.89	11.14	15.44
MnO	0.14		0.13	0.14	0.08	0.09	0.15	0.37
MgO	49.29	49.31	32.28	33.36	14.40	18.12	20.61	16.29
CaO	0.06	0.09	0.68	1.11	20.78	21.01		
Na_2O			0.11	0.08	1.95	0.37		
Total	100.96	99.52	99.05	99.35	99.56	99.50	100.19	99.36
Cation	Mg_{89}	Mg_{91}	Mg_{88}	Mg_{89}	Mg_{46}	Mg_{52}	Mg_{67}	Cr_{46}
ratio %	Fe_{11}	Fe_9	Fe_{11}	Fe_9	Ca_{48}	Ca43	Fe20	Mg35
			Ca_1	Ca_2	Fe_6	Fe_5	Cr_{13}	Fe_{19}

SML Spinel-metalherzolite SMH Spinel-metaharzburgite. Analyst L. R. Raynor.

Calculated bulk rock compositions, based on modal proportions of mineral phases

Rock	SML	SMH	SML (ol 75%, opx 15%, cpx 5%, spl 5%)
SiO_2	40.93	43.57	SMH (ol 78.5%, opx 20%, spl 1%, cpx 0.5%)
TiO_2	0.16	0.02	
Al_2O_3	4.06	0.89	
Cr_2O_3	0.41	0.58	
FeO total	10.07	8.46	
MnO	0.14	0.03	
MgO	43.56	45.65	
CaO	1.14	0.40	
Na_2O	0.12	0.02	
Total	100.59	99.62	

TABLE 4
Comparative representative analyses, metawebsterites and mica-metawebsterite

Mineral/	Clinopyroxene			Orthopyroxene			Mica
rock type	MW(WW14)	MW(WW16)	MW(WW6)	MW(WW14)	MW(WW16)	MW(WW6)	MW(WW6)
SiO_2 wt%	49.85	49.87	52.08	52.71	52.83	55.01	36.69
TiO_2	1.17	1.08	0.23	0.35	0.34		4.38
Al_2O_3	7.86	7.50	7.12	5.40	5.53	4.90	16.85
Cr_2O_3	0.29	0.40	0.75	0.17	0.23	0.24	0.49
FeO total	7.27	6.22	3.10	12.52	10.82	6.90	4.77
MnO	0.16	0.15		0.19	0.18		
MgO	14.21	14.41	14.28	27.70	28.55	32.11	19.87
CaO	16.94	17.36	19.60	1.11	1.21	0.71	0.15
Na_2O	2.27	2.03	1.87	0.25	0.16		0.35
K_2O							8.50
Total	100.02	99.02	99.03	100.40	99.85	99.87	92.05
Cation	Mg_{48}	Mg_{48}	Mg_{47}	Mg_{79}	Mg_{81}	Mg_{88}	Mg_{80}
ratio %	Ca_{40}	Ca_{41}	Ca_{47}	Fe_{19}	Fe_{17}	Fe_{11}	Fe_{11}
	Fe_{12}	Fe_{11}	Fe_6	Ca_2	Ca_2	Ca_1	Ti_9

MW Metawebsterite (WW14, WW16). WW14 cpx av. 4 analyses, opx av. 4 analyses; WW16 cpx av. 8 analyses, opx av. 5 analyses. Analyst L. R. Raynor.

MW Mica + apatite-bearing metawebsterite (WW6). Analyst F. L. Sutherland.

Calculated bulk rock compositions, based on modal proportions of mineral phases

Rock	WW14	WW16	WW6
SiO_2wt%	51.28	51.36	52.33
TiO_2	0.76	0.71	0.22
Al_2O_3	6.63	6.52	7.01
Cr_2O_3	0.23	0.31	0.72
FeO total	9.90	8.52	3.30
MnO	0.18	0.17	
MgO	20.96	21.49	15.18
CaO	9.03	9.29	18.66
Na_2O	1.26	1.10	1.78
K_2O			<0.05
P_2O_5			<0.05
Total	100.23	99.47	99.20

WW14 (cpx 50%, opx 50%)
WW16 (cpx 50%, opx 50%)
WW6 (cpx 95%, opx 5%, phl < 0.5%, ap < 0.5%)

TABLE 5
Comparative representative analyses, garnet-two pyroxene assemblages

Mineral/rock type	Clinopyroxene GW(WW8–WW13)	Orthopyroxene GW(WW8–WW13)	Garnet GW(WW8–WW13)	Spinel GW(WW12–13)
SiO_2	49.47–50.24	51.53–52.41	40.49–41.28	
TiO_2	1.28–1.40	0.40–0.50	0.45–0.59	0.76–0.80
Al_2O_3	8.05–8.36	5.58–5.98	22.54–22.99	58.26–59.31
Cr_2O_3	0.00–0.25	0.03–0.15	0.06–0.40	0.41–2.36
FeO total	7.21–7.71	12.46–12.95	12.35–13.66	21.47–22.76
MnO	0.00–0.16	0.15–0.19	0.33–0.41	0.08–0.13
MgO	13.77–14.10	27.26–27.94	16.98–17.45	16.68–16.81
CaO	16.62–16.93	1.12–1.28	5.09–5.26	0.00–0.02
Na_2O	2.05–2.28	0.16–0.24		
K_2O				
Total	99.48–100.34	99.68–100.88	99.82–100.53	99.58–100.17
Cation ratio %	Mg_{45-47} Ca_{40-41} Fe_{13-14}	Mg_{77-78} Fe_{19-20} Ca_{2-3}	Mg_{60-61} Fe_{26-27} Ca_{13-14}	Mg_{56-60} Fe_{40-43} Cr_{1-4}

GW Garnet-websterite (± spinel). WW8-WW10; cpx av. 5–13 analyses, opx av. 4–8 analyses, grt av. 5–6 analyses. GW (WW12–13) cpx av. 8 analyses, opx av. 4 analyses, grt av. 8 analyses, spinel av. 2-3 analyses. Analyst L. R. Raynor.

(En_{57-58}) and the spinel is ulvospinel (Usp_{92-93} Mf_{5-6} Sp_{1-2} Mc_{0-1}) (table 7).

The other granulite is a fine-grained, slightly foliated assemblage composed of plagioclase (35%), cpx (30%) and opx (25%) forming strongly polygonal recrystallisations in grains mostly 0.5–1 mm across (pl. 1H). The large pyroxenes show strain lamellae and undulose extinction and the cpx is pleochroic. The plagioclase is distinctly calcic (An_{73-75}); the cpx is Al-rich diopside (Wo_{48-49} En_{40-41} Fs_{11-12}), the opx is moderately Fe-enriched (En_{68-70}) and small interstitial accessory minerals (10%) include orange-brown rutile (5%) altered on rims and cleavages to opaque Mg-rich ilmenite, pargasitic amphibole, Ti-rich phlogopite and rare corundum (table 7).

Secondary Minerals

The garnet-bearing assemblages show varied degrees of reaction of the garnet, which alters to cloudy, fine-grained admixtures of spinel and feldspar containing secondary spl, opx and rarely cpx grains. The spl is pleonaste (Sp_{67-74} Hc_{23-30} Mt_{2-3} Usp_{0-1} Cm_{0-1}), the opx is moderately Fe-enriched (En_{75-79}) and cpx is Al-rich augite (En_{49-50} Wo_{37-38} Fs_{13}) (table 8). The Ca-contents in the opx (Wo_{3-4}) suggest relatively high temperature reactions were involved in their formation (Brey & Köhler 1990) while up to 0.7% Na_2O in the cpx suggests a metasomatic component helped in the garnet breakdown. The steps involved in such breakdown reactions were detailed in Griffin *et al.* (1984).

Secondary amphibole forms brown infillings between spl and cpx grains in a garnet-spinel-metaclinopyroxenite. It is kaersutite in composition, distinctly more Ti-rich than the gedritic amphibole that mantles cpx in the same assemblage, and may derive from fluid infiltrations from the host melt.

Thermobarometry

Several thermometers and barometers were used to investigate temperature (T) and pressure (P) conditions for metamorphic re-equilibration in the xenolith assemblages. Previously reported couplings (Ellis & Green 1974 T and Wood 1974 P; Brey & Köhler 1990 TP) for Table Cape (Sutherland *et al.* 1994) are not further considered because of apparent compositional and experimental incompatibilities, discussed later. The Wells (1977) two- pyroxene thermometry, with appropriate allocations of Fe^{2+} and Fe^{3+}, provides good results at T < 1300°C, with uncertainties in the precision within ± 50°C (Tribaudino & Bruno 1993, Taylor 1998). This gives a thermal ordering of re-equilibration temperatures (quoted to the nearest 5°C) for the Table Cape vent meta-assemblages. The method gives a range of 1055–1070°C for garnet (± spinel)-metawebsterites and metawebsterites, 810–1080°C for spinel-metaperidotites, 950–960°C for mica (± apatite)-metawebsterites and 860–870°C for granulites. The relatively wide spinel-metaperidotite temperatures overlap those for the granulites and some metawebsterites and can be refined further using the Sachtleben & Seck (1981) and Witt-Eickschen & Seck (1991) thermometric methods. This gave likely T ranges between 915–1010°C for the spinel-lherzolite and 965–1075°C for the spinel-bearing harzburgite, which preserves the relative ordering for these assemblages established with the Wells thermometer. The modified metaperidotite T results also delineate the crustal granulite range (< 900°C) from the mantle T range (> 900°C) and suggest the crust-mantle boundary (MOHO) intersected an ambient geotherm at around 900°C (fig. 2).

The garnet-metawebsterites permit three-phase thermobarometry. This study used the Wells (Fe^{3+}) two-pyroxene thermometric results with the Wood (1974) garnet-orthopyroxene barometer. This coupling provides a narrow TP range for these assemblages (1050–1070°C; 1.22–1.36 GPa), compatible with the tight compositional range for the assemblage analyses and the experimental spinel-pyroxenite/

TABLE 6

Comparative representative analyses, garnet-metawehrlite and metaclinopyroxenite

Mineral/	Clinopyroxene		Garnet		Olivine	Spinel		Amphibole
Rock type	GW	GC	GW	GC	GW	GW	GC	GC
SiO_2	49.41	49.66	41.52	41.00	39.18	0.29	0.29	43.89
TiO_2	1.47	1.43	0.43	0.49		0.62	0.24	0.74
Al_2O_3	9.14	8.35	23.41	23.11		61.01	65.17	19.01
Cr_2O_3	0.02		0.03		0.03	0.47	0.18	
FeO total	6.65	7.68	12.08	13.61	17.49	19.62	15.66	12.67
MnO	0.07		0.30	0.32	0.16	0.13	0.15	0.26
MgO	13.66	13.84	17.70	17.08	42.96	18.20	19.02	16.63
CaO	17.60	17.21	5.30	5.31	0.20			4.00
Na_2O	2.07	1.98						0.57
K_2O								0.58
Total	100.09	100.15	100.77	100.92	100.02	100.34	100.71	98.35
Cation	Mg_{46}	Mg_{45}	Mg_{63}	Mg_{60}	Mg_{81}	Mg_{62}	Mg_{68}	Mg_{62}
ratio %	Ca_{42}	Ca_{41}	Fe_{24}	Fe_{27}	Fe_{19}	Fe_{37}	Fe_{32}	Fe_{27}
	Fe_{12}	Fe_{14}	Ca_{13}	Ca_{13}		Ti_1	Ca_{11}	

GW Garnet-spinel metawehrlite (WW4). Analyst L. R. Raynor. GC Garnet-amphibole-metaclinopyroxenite (WW15). Analyst B. J. Barron.

Calculated bulk rock compositions, based on modal proportions of mineral phases

Rock	WW4	WW15	WW4 (grt 42.5%, cpx 37.5%, spl 10%, ol 10%)
SiO_2wt%	40.13	41.66	WW4 (cpx 55%, grt 35%, spl 10%)
TiO_2	0.79	1.00	
Al_2O_3	19.48	19.18	
Cr_2O_3	0.07	0.01	
FeO total	11.33	10.58	
MnO	0.19	0.11	
MgO	18.76	15.59	
CaO	8.87	11.33	
Na_2O	0.78	1.09	
Total	100.40	100.55	

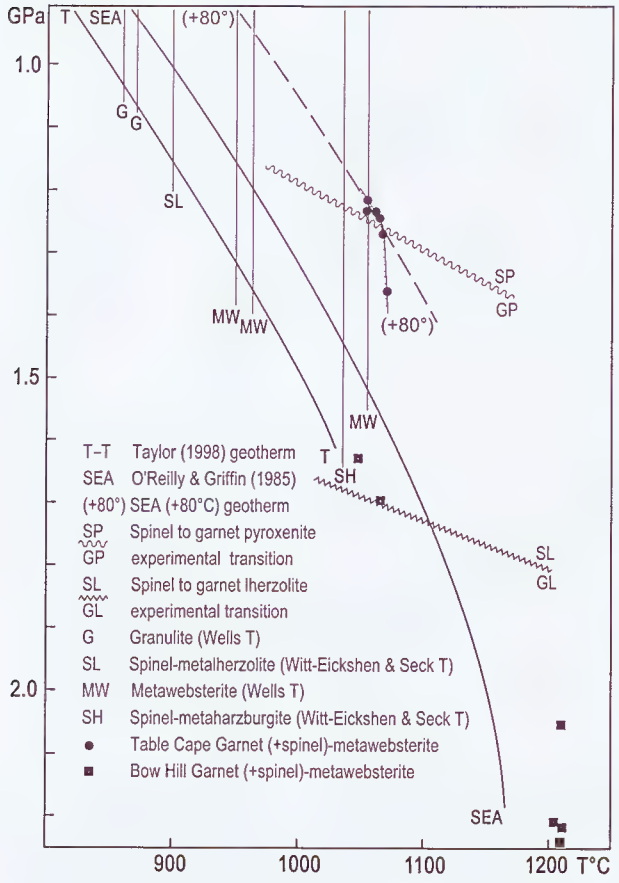

FIG. 2 — Temperature (T °C)-Pressure (GPa) diagram, relating Table Cape (Wells T, Wood P) and Bow Hill (Taylor TP) plots to experimental spinel to garnet pyroxenite and spinel to garnet lherzolite phase transitions. Re-equilibration temperature lines for two-pyroxene granulites and metawebsterites (Wells T) and metaperidotites(Witt-Eickschen & Seck T) are indicated to show intersections on different south-eastern Australian geotherms. The TP points for Table Cape garnet (± spinel)-websterites are 1060°C, 1.23GPa (WW8); 1065°C, 1.24GPa (WW9); 1055°C, 1.23GPa (WW10); 1070°C, 1.36GPa (WW12), 1065°C, 1.27GPa (WW13). The Wood barometry uses the Cr-Na-Al modification. The TP points for Bow Hill garnet (± spinel)-lherzolites and garnet-websterite are 1048°C, 1.63 GPa (DR12508), 1065°C, 1.69 GPa (DR 12501), 1205°C, 2.21GPa (EBH-E), 1213°C, 2.22GPa (EBH-D); 1210°C, 2.24GPa (BHS); 1212°C, 2.05GPa (QQ20a).

garnet-pyroxenite transition (fig. 2). The Table Cape TP results are 60–85°C higher at equivalent pressures than for the Southeast Australian (SEA) geotherm of O'Reilly & Griffin (1985), based on Ellis & Green (1979)T with Wood (1974) P, and 110–135°C higher than for the revised SEA geotherm, using Taylor (1998) TP (fig. 2). This reinforces conclusions from previous thermobarometry for the Table Cape vent suite that suggest a relatively hotter Cenozoic geotherm for the Tasmanian lithosphere (Sutherland *et al.* 1994), but the new thermobarometry provides a more controlled result.

DISCUSSION

The Table Cape vent xenoliths allow partial insights into the underlying lower crust-upper mantle lithology and its thermal state when sampled by a Mid-Miocene nephelinitic melt. The host nephelinite was fractionated prior to the eruptive sampling and this evolution took place at TP conditions exceeding those estimated for the deepest contained mantle xenoliths (i.e., > 1070°C and 1.4 GPa).

Host Evolution

The host nephelinite has generally low Zr/Nb (4.0), Rb/Sr (0.017), Ba/Nb (2.2) and Ba/Th (26) ratios, which link it to nephelinites of the low Rb and Ba group in Tasmania (e.g., West Scottsdale, Northeast Tasmania; see Sutherland *et al.* 2004). These particular nephelinites are attributed to low degrees of partial mantle melting in which some phlogopite is retained in the mantle source. In this respect, the Table Cape vent nephelinite differs from the nearby, but older, nephelinite at Boat Harbour, which relates to the high Ba and Rb group (Sutherland *et al.* 1996). Similar nephelinites to the Table Cape vent melt represent initial melts with liquidus temperatures around 1250–1300°C at 2.4–3.5 GPa based on experimental work on Tasmanian examples from Lughrata and Scottsdale (Tilley & Thompson 1972, Frey *et al.* 1978, Adam 1990). The experiments on the Scottsdale nephelinite suggest such melts with only slightly (1–2 wt%) higher SiO_2 can be generated from garnet lherzolite mantle that contains volatile (H_2O + CO_2) concentrations of 6.5 wt% at 3.4 GPa (Adam 1990).

The precise high pressure mineral phases that crystallised during evolution of the erupted Table Cape vent melt are difficult to completely designate. They probably include clinopyroxene similar to the Mg-rich augite megacrysts (see Adam 1990, fig. 7), Other potential phases such as olivine, spinel and garnet may be difficult to distinguish in composition from those released from disaggregated mantle xenoliths, although some cases may be distinguished texturally and based on inclusions.

Assemblage Affinities

The xenoliths include mantle metaperidotites and meta-pyroxenites and crustal granulites, but their chemical characterisations are handicapped by lack of sufficiently large and fresh samples for analysis within the altered pyroclastic deposits. Only garnet-metapyroxenite and granulites were found suitable for conventional analyses (Sutherland *et al.* 2004). Approximate bulk compositions, however, were calculated from small, fresh samples by using estimated proportions of mineral phases analysed by EMP, using a visual grid.

The metaperidotites show significant olivine alteration in larger xenoliths, but compositions were estimated from mineral analyses in fresh spinel-metalherzolite and metaharzburgite (table 3). These suggest the metalherzolite is enriched in Al, Fe, Ca and Na and depleted in Si relative to the harzburgite. 'Mantle' CIPW norms based on the analyses, after Wilkinson & Stolz (1997), gave reasonable matches with the modal mineralogy, showing higher Ca-tschermakite in the metalherzolite (Cats 4.4 *cf* 1.5 wt%) and higher Hy in the metaharzburgite (22.8 *cf* 13.5 wt%). The higher

TABLE 7
Comparative representative analyses, two-pyroxene granulites

Mineral/	Clinopyroxene		Orthopyroxene		Plagioclase		Amphibole	Mica
rock type	BG(WW1)	MG(WW3)	BG(WW1)	MG(WW3)	BG(WW1)	MG(WW3)	MG(WW3)	MG(WW3)
SiO_2 %	50.99	50.71	50.80	52.67	53.58	49.69	42.34	37.52
TiO_2	0.22	0.56	0.14				2.92	5.45
Al_2O_3	3.70	4.94	1.79	2.49	29.78	32.84	14.27	15.82
Cr_2O_3		0.23					0.27	
FeO total	10.53	6.57	26.25	19.49			10.32	10.52
MnO	0.15		0.51	0.23				
MgO	12.15	13.35	20.09	24.24			13.35	14.78
CaO	21.79	22.12	0.43	0.54	12.08	15.11	11.69	3.23
Na_2O	0.47	0.48			4.64	2.86	1.57	0.65
K_2O					0.11	0.21	2.11	6.00
Total	100.00	98.96	100.01	99.66	100.19	100.71	98.84	93.97
Cation	Ca_{46-47}	Ca_{48-49}	Mg_{57-58}	Mg_{68-69}	Ca_{58-59}	Ca_{73-74}	Mg_{48-49}	Mg_{63}
ratio%	Mg_{36}	Mg_{40-41}	Fe_{41-42}	Fe_{30-31}	Na_{40-41}	Na_{25-26}	Ca_{30-31}	Fe_{25}
	Fe_{17-18}	Fe_{11-12}	Ca_1	Ca_1	K_{0-1}	K_{1-2}	Fe_{21}	Ti_{12}

BG Banded granulite (WW1), includes ulvospinel (Fe_{66} Ti_{29} Mg_5). MG Micro-granulite (WW3), includes rutile with Mg-rich ilmenite rims (Ti_{50} Fe_{29} Mg_{21}). Analyst F. L. Sutherland.

TABLE 8
Comparative representative analyses, secondary phases, garnet-pyroxene and pyroxene assemblages

Mineral/	Cpx	Opx	Opx	Opx	Spl	Spl	Spl	Spl	Amp
rock type	WW4	WW4	WW9	WW15	WW9	WW12	WW14	WW15	WW15
SiO_2 wt%	48.36	52.17	48.46	50.06	0.25			0.34	36.12
TiO_2	0.68	0.23	0.39	0.54	0.21	0.14	0.22	0.19	5.45
Al_2O_3	11.00	8.17	11.00	10.81	63.98	65.08	64.53	65.00	6.84
Cr_2O_3	0.04	0.04	0.22	0.02	1.18	0.39	0.35	0.13	0.02
FeO total	7.17	11.03	12.27	10.50	16.48	15.02	17.27	14.85	19.70
MnO	0.28	0.27	0.36	0.27	0.23	0.13	0.17	0.16	0.28
MgO	15.34	26.82	24.95	26.66	18.30	19.17	17.85	19.55	13.28
CaO	16.11	1.86	1.68	1.75					6.80
Na_2O	0.68	0.18	0.09	0.11					1.22
K_2O									1.50
Total	99.66	100.77	99.42	100.72	100.63	99.93	100.39	100.22	91.21
Cation	Mg_{49-50}	Mg_{78}	Mg_{75-76}	Mg_{78-79}	Mg_{64-65}	Mg_{69-70}	Mg_{64-65}	Mg_{70}	Mg_{45-46}
ratio %	Ca_{37-38}	Fe_{18}	Fe_{20-21}	Fe_{17-18}	Fe_{31-32}	Fe_{30-31}	Fe_{35}	Fe_{30}	Fe_{37-38}
	Fe_{13}	Ca_4	Ca_{3-4}	Ca_{3-4}	Cr_{4-5}	Ti_{0-1}	Cr_{0-1}	Ti_{0-1}	Ca_{16-17}

Cpx (clinopyroxene). Opx (orthopyroxene). Spl (spinel). Amp (amphibole)
WW4 Garnet-metawehrlite. WW9 Garnet-metawebsterite. WW12 Garnet-spinel-metawebsterite. WW14. Metaclinopyroxenite. WW15 Garnet-amphibole-metawebsterite. Analyst L. R. Raynor.

$Mg/(Mg+Fe^{2+})$ for the metaharzburgite (0.923) compared to metalherzolite (0.906) indicates its more depleted nature. Two potential sources exist for the metaharzburgite xenolith. One is a highly-depleted mantle component, while the other is a higher level fragment derived from an underlying, unexposed Cambrian ultramafic complex as seen outcropping elsewhere in northwestern Tasmania (Brown 1988). Cambrian harzburgites, however, contain Cr-rich spinels with higher $100xCr/(Cr+Al)$ and $100xMg/(Mg+Fe^{2+})$ values (Brown 1988, fig. 8) than the Table Cape vent metaharzburgite (Cr value 0.50, Mg value 0.65). This favours a separate origin for the metaharzburgite, which although a scarce lithology in Southeast Australian mantle peridotite suites, can be significant at rare sites (e.g., Mt Leura, Victoria; Chen *et al.* 1989). The calculated bulk analysis and mineralogy for the Table Cape vent metaharzburgite match those of the high Mg value (0.92–0.93) Mt Leura harzburgites, rather that the lower Mg value (0.87–0.90) harzburgites that Chen *et al.* (1989) interpreted as cumulates. The Table Cape vent metaharzburgite pyroxenes have higher Ca in the opx and lower Na and Al in the cpx than the Mt Leura examples. They seem a deeper, higher T variant than at Mt Leura where they dominate in the uppermost mantle zone.

Garnet-metawebsterites dominate the Table Cape vent garnet-metapyroxenites. A bulk analysis gives a relatively low Si, high Mg composition (Sutherland *et al.* 2004) but with significantly lower $Mg/(Mg+Fe^{2+})$ than for the metaperidotites (0.79 *cf* 0.90). The 'mantle' norm is dominated by Hy (37%) and Cats (33%), with subordinate Ol (12%). This suggests a recrystallised mafic parental cumulate, either from transitional olivine basalt or olivine tholeiite composition. The high Ni (419 ppm) and Cr (387 ppm) and low Zr (47 ppm), Ba (7 ppm) and Rb (3 ppm) are compatible with a relatively mafic cumulate or little fractionated basalt melt. Although high Ni and Cr can be introduced by mantle wall rock-melt interactions (O'Reilly *et al.* 1989), this is considered unlikely here as no composite xenoliths are evident. The present neoblastic assemblage of cpx, opx, spl and grt formed from progressive recrystallisation of an original magmatic parent along reactions similar to those outlined from western Victorian suites (O'Reilly *et al.* 1989). The rarer wehrlites and olivine-bearing clinopyroxenite at Table Cape vent may represent less re-constituted lithologies or possibly assemblages derived from more alkaline parental melts. Their calculated bulk compositions (table 6) and 'mantle' norms (Cats 34-37, Hy 35-37, Ol 9-16 wt%) overlap those of garnet-metawebsterites. The Table Cape garnet-metapyroxenites are essentially 'dry' assemblages and differ from the hydrous amphibole-mica-bearing suites in some SE Australian xenolith suites (e.g., Bullenmerri, Gnotuk, Anakie East; Graham *et al.* 2003). They also differ in mineral and bulk compositions from 'dry' garnet-metapyroxenite suites that typify many eastern Australian suites (Irving 1974, Stolz 1984, Griffin *et al.* 1987), in being more Fe-rich. Relatively little experimental work is available on Australian garnet-metawebsterites, except for an Fe-poor Delegate example (Irving 1974). This work gave a TP point for the co-existing grt, cpx and opx at 1200°C and 1.5 GPa, which lies on the high T side (fig. 2) of the Table Cape vent Fe-rich metawebsterite re-equilibration conditions (1055–1100°C, 1.2–1.4 GPa).

Metawebsterites, lacking garnet, form a minor component at Table Cape vent and include two distinct types. The more common type consists of a polygonal-textured pyroxene mosaic with opx compositions that overlap those in the garnet (± spinel)-metawebsterites (see tables 4 and 5). This suggests links between these two assemblages. Calculated bulk analyses, however, are notably higher in Si and Mg and lower in Al and Fe for the metawebsterites (table 4) and give 'mantle' norms with high Hy (51 wt%), moderate Di (26 wt%), minor Cats (10 wt%) and negligible or no Ol. This suggests a tholeiitic parental affinity, unless the metawebsterites are only pyroxene-rich parts from inhomogeneous garnet (± spinel)-metawebsterite bodies. Alternatively they may be recrystallisations of coarse subcalcic clinopyroxenites, originally crystallised as liquidus precipitates, as proposed for some metawebsterite xenoliths near Glen Innes, New South Wales (Wilkinson & Stolz 1997). This origin is favoured by mutual unmixing in the pyroxenes and a bulk recalculated composition close to that of a subcalcic clinopyroxene. The Table Cape vent metawebsterites, however, have lower Ca and higher Ti than in the Glen Innes subcalcic clinopyroxene (table 4, *cf* with Wilkinson & Stolz, tables 5 and 10). In contrast, the other type of Table Cape vent metawebsterites approach Cr-bearing diopside in composition (table 4) and are higher in Ca and lower in Mg and Fe than the Ti-Al-rich websterites. The accessory Ti-bearing phlogopite and apatite suggest an introduced metasomatic component enriched in Ti, K and P. The cloudy apatite resembles that in diopsidic vein material within metasomatised metalherzolites in south-eastern Australia (O'Reilly & Griffin 2000). Such mantle apatites in southeastern Australian xenoliths come from a relatively young metasomatic event, originally assigned to a deep (plume-related) fluid. Re-examination of the apatite neon isotope data, however, now suggests it derives from Mid-Ocean Ridge Basalt (MORB) fluids rather than a primitive plume source (Gautheron & Moreira 2003).

The crustal granulites are two-pyroxene, Ca-rich feldspar assemblages and include both anhydrous and hydrous metasomatised types. An anhydrous banded granulite (Sutherland *et al.* 2004) corresponds chemically to a transitional olivine tholeiite. It equates to a basalt protolith (SiO_2 51, Di 25, Hy 22, Ol 4 wt%) of relatively unfractionated nature, with $Mg/(Mg+Fe^{2+})$ = 0.67 and An/(An+Ab) = 0.59. The hydrous micro-granulite exhibits a diverse accessory mineralogy that includes Ti-bearing amphibole and mica, rutile-ilmenite and rare corundum. It is even more Mg-rich and primitive in its features than the anhydrous granulite, with $Mg/(Mg+Fe^{2+})$ = 0.74 and An/(An+Ab) = 0.68, high Ni+Cr (522 ppm) and low Zr (53 ppm) contents. It also corresponds to transitional olivine basalt in its SiO_2 (50 wt%) and other normative contents (Hy 32, Di 9, Ol 2 wt%). The accessory minerals and textures suggest modification of a basaltic parent by volatile, Al, Ti, Fe and K-bearing fluids prior to metamorphic re-equilibration.

The garnet-metawebsterites and two-pyroxene granulites in the Table Cape vent suite suggest transitional olivine basalt protoliths were emplaced at both mantle and crustal levels. Normative wt% ratios for these rocks (Hy 44-75, Di 20-48, Ol 8-23) plot across relatively unoccupied positions in the Ol-Di-Hy normative tetrahedron for eastern Australian assemblages (O'Reilly *et al.* 1989). This supports an unusual lithospheric section below Table Cape, in keeping with the moderately Fe-rich pyroxene mineralogy in these assemblages. The Table Cape vent calcic plagioclase granulites differ from granulite in the Boat Harbour section, which contains Na-rich plagioclase (Sutherland *et al.* 1996).

Although more silica-saturated protoliths dominate the Table Cape vent Al-Ti-bearing augite suites, rare metawehrlite and garnet-metaclinopyroxenites suggest more olivine-rich and perhaps even alkaline progenitors may have been present.

Tasmanian/East Australian Geotherms

The SEA geotherm was established using Ellis & Green (1979) grt-cpx exchange thermometry, which, while accommodating Fe^{2+} and Fe^{3+} assignments in the minerals, generally leads to wider temperature differences between these allocations than does the Wells thermometry (Griffin *et al.* 1984, O'Reilly & Griffin 1985). The Ellis & Green thermometer, however, has proved unreliable in its application. It generally overestimates T relative to experimental results for the TP range for such xenolith suites (see Sutherland *et al.* 1994, 1998, Ai 1994, Taylor 1998) or is erratic where Ca exceeds a concentration of 0.15 atoms in the garnet (Alaoui *et al.* 1997). The Table Cape vent garnets all have Ca <0.15, but application of Ai (1994) thermometry nevertheless gives highly erratic results. For these reasons, grt-cpx exchange thermometry is abandoned for the Table Cape vent grt-bearing assemblages, in favour of Wells thermometry. The comparison in T range between Ellis & Green (Fe^{3+}) and Wells (Fe^{3+}) for Table Cape vent grt-websterites is 1005–1220°C and 1055–1075°C respectively, which leads to corresponding differences in P estimates when inserted into the Wood barometer (e.g., 0.74–1.86 GPa, Sutherland *et al.* 1994, *cf* 1.23–1.36 GPa, Sutherland *et al.* 2004).

Wood (1974) barometry, however, is retained for the Table Cape vent study as a suitable barometer for Fe-rich grt-metawebsterites, particularly as some other potential barometers were experimentally calibrated against more Mg-rich assemblages. This includes Taylor (1998) thermobarometry, which provides a lower intersection than the original SEA gradient. The new Table Cape vent thermobarometry indicates a coherent grouping for grt-websterites near the base of the sampled mantle section at temperatures well above SEA (fig. 2). The Table Cape vent TP section extends to 45 km depth, so represents a higher level section than at Bow Hill, Tasmania, which extends into the spinel-garnet-metalherzolite transition.

The Mg-rich Bow Hill grt-assemblages (Sutherland *et al.* 1984) need different thermobarometry than for Table Cape assemblages. With Wells (1977) thermometry (with only Fe^{2+} allocated) and Wood (1974) barometry, the wide range of results (1000–1180°C, 1.0–2.5 Gpa) extend well beyond the experimental garnet-spinel lherzolite transition zone, suggesting an unsuitable coupling. The Taylor (1998) TP method, which gives T estimates closest to Wells T, was chosen as a more appropriate coupling. In calculating TP, Fe^{2+} and Fe^{3+} was allocated in the garnets (Ca concentration 0.12 to 0.14 atoms) by charge balance and in the pyroxene by the cation allocation method of Cawthorn & Collerson (1974). The results (I. Roach, Australian National University, pers. comm. 2004) range from 1048–1065°C, 1.63–1.69 GPa (grt-spl-metalherzolite) to 1205–1213°C, 2.21–2.24 GPa (grt-metalherzolite) and 1213°C and 2.05 GPa (grt-metawebsterite). These results lie on the high T side of the Taylor (1998) modified SEA geotherm (T-T, fig. 2) and the higher P assemblages even lie above the original SEA geotherm. Thus, both Table Cape and Bow Hill suites suggest that extreme geothermal gradients existed in the Tasmanian Miocene lithosphere.

The precise profiles and extent of variations within Mesozoic-Cainozoic East Australian geotherms have engendered debate as to whether the TP profiles overestimate the data or mark more conservative profiles, depending on the choice of thermometer/barometer couplings and other effects (McDonough *et al.* 1991, Sutherland *et al.* 1994, 1998, O'Reilly *et al.* 1997, Sutherland 1999, Gaul *et al.* 2003, Roach 2004). Various protocols for thermometer and barometer usage in general, that incorporate differences in mineralogical compositions of assemblages, have been proposed (O'Reilly *et al.* 1997, Xu *et al.* 1998, Smith 1999). These suggested couplings do not include some well-based newer couplings (Taylor 1998 TP). Thus, uncertainties exist in geotherm comparisons for the East Australian/East Asian xenolith suites. In a study of xenoliths in Miocene basalts from northern China, Chen *et al.* (2001) preferred Brey & Köhler (1990) TP for the Mg-rich garnet-websterites, rather than the Ellis & Green (1979) and Wood (1974) TP, and the results clearly plot well above the SEA geotherm which was based on the latter coupling. However, they retained Ellis & Green T and Wood P for an Fe-rich garnet-metawebsterite, which placed this plagioclase-bearing assemblage at over 70km depth, well-divorced from the other TP plots.

Despite the complications in selecting thermobarometric methods, the two revised Tasmanian Miocene geotherms both suggest elevated gradients that exceed both SEA and the modified SEA (T-T, fig. 2) gradients. This supports a range of gradients for eastern Australian Mesozoic-Cenozoic geotherms, going from cooler gradients (e.g., Mesozoic Ruby Hill and Jugiong suites; Sutherland 1999, Gaul *et al.* 2003) into higher gradients (e.g., Cenozoic western Victoria SEA; O'Reilly *et al.* 1997, Taylor 1998) and some more extreme gradients (e.g., Cenozoic Tasmania, this study). The exact geotherm gradient becomes critical when correlating other lithological temperatures, uncontrolled by pressure, as for spinel-metalherzolites, garnet-metaclinopyroxenites and non-garnetiferous granulites, leading to potential depth uncertainties in crust-mantle sections (Sutherland *et al.* 1998).

Some temperature intervals for Table Cape vent assemblages are shown in relation to the TP controlled segments of Tasmanian Miocene geotherms (fig. 2). The spinel-metalherzolite T ranges at Table Cape intersect at up to 1.15 GPa on the modified SEA geotherm, up to 1.0 GPa on the SEA geotherm and extrapolate to 0.8 GPa on a geotherm 80°C higher than SEA. Similarly, granulites at Table Cape intersect at up to 1.05 GPa on modified SEA, up to 0.9 GPa on SEA and extrapolate to 0.75 GPa on SEA + 80°C geotherms. These potential differences in lithological assignments (0.3 GPa) graphically illustrate their dependence on the precise geotherm, and are further complicated by pressure-dependant variation in metaperidotite T estimates using Witt-Eickschen & Seck (1991) thermometry.

The seismic data for the Table Cape region suggests a Moho depth at 32 km (Rawlinson *et al.* 2001), i.e., 1.05–1.1GPa, which would give T intersections of 870°C on modified SEA, 920°C on SEA and 1000°C on SEA + 80°C geotherms. The first two T intersections are compatible (within error) with the Table Cape granulite-metalherzolite interval (870–915°C), but less so for the SEA (+80°C) geotherm. Thus, an apparent discrepancy exists between more elevated gradients in the lower (grt-metawebsterite) part of the section and reduced gradients at the mantle-crust transition zone. Unless all the thermobarometry (past and present) on Table Cape garnet-metapyroxenites is seriously

in question, this implies a localised thermal anomaly.

One possibility for such a thermal anomaly is local heating of mantle adjacent to magma chambers. Such mantle magma chambers exist nearby at Boat Harbour, where basanite magmas were fractionated to erupt as lherzolite-bearing nepheline mugearites (Sutherland *et al.* 1996). The Boat Harbour fractionated lavas are dated at 14.2 ± 0.1 Ma, just prior to eruption of the Table Cape centre (minimum 13.3 ± 0.2 for late stage lavas). Thus, additionally heated mantle may have already been present when fractionated olivine nephelinite brought up the Table Cape xenolith suite. This scenario would represent small-scale local perturbation of a prevailing geotherm, within a limited segment of the lithosphere. It would contrast with the western Victorian scenario where extensive basaltic intrusions around the mantle-crust boundary were identified on seismic sections and were considered to generate the SEA geotherm (Cull *et al.* 1991). The Bow Hill TP plots also suggest a declining geothermal gradient, so that thermal contribution from deep mantle magma chambers that fractionated the host nepheline hawaiite there also needs consideration.

SYNTHESIS

The Table Cape vent xenolith suite (erupted with evolved nephelinite) represents a unique lithospheric section, both within Tasmania and elsewhere among eastern Australian xenolith suites. It is one of two known garnet-bearing (two-pyroxene) xenolith suites in Tasmania, but represents a higher level mantle section with more Fe-rich minerals in the assemblages than occurs at Bow Hill.

Revised thermobarometry for Tasmanian garnet-bearing xenoliths confirmed that the associated Miocene geotherms in part exceeded the western Victorian (SEA) gradient.

Considerations of xenolith temperatures for the crust-mantle boundary lithology at Table Cape, in relation to the seismic Moho (32 km depth) and proposed SEA and Table Cape geotherms, suggest the Table Cape geotherm may mark a locally highly perturbed gradient.

The Table Cape geotherm may reflect thermal input from adjacent magma chamber activity that gave 14 Ma Boat Harbour fractionated basalts, prior to Table Cape activity.

Xenolith-derived geotherms related to Mesozoic-Cenozoic basaltic activity have been constructed from many eastern Australian and Asian sites. However, not only do they involve complications in thermobarometry in defining such geotherms, but also incorporate diverse magmatic thermal inputs that may include localised effects.

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REPRODUCTIVE ECOLOGY OF THE MOUNTAIN DRAGON, *RANKINIA (TYMPANOCRYPTIS) DIEMENSIS* (REPTILIA: SQUAMATA: AGAMIDAE) IN TASMANIA

by Jemina Stuart-Smith, Roy Swain and Andrew Welling

(with three tables and two text-figures)

Stuart-Smith, J., Swain, R. & Welling, A. 2005 (16:xii): Reproductive ecology of the Mountain Dragon, *Rankinia* (*Tympanocryptis*) *diemensis* (Reptilia: Squamata: Agamidae) in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 139: 23–28. ISSN 0080–4703. School of Zoology, University of Tasmania, Private Bag 5, Tasmania, 7001 Australia.(J.S-S.*, R.S., A.W.). *Author for correspondence.

The mountain dragon, *Rankinia (Tympanocryptis) diemensis* (Gray, 1841), is the only member of the Agamidae in Tasmania. It occurs in some of the coldest regions occupied by any dragon in Australia, and is found in a variety of habitats ranging from coastal heath to alpine scrub. This paper examines the reproductive ecology of *R. diemensis* in the most southerly range of its distribution, providing baseline data on timing of reproductive events, reproductive cycles, nesting behaviour and ovipositioning, clutch characteristics and incubation conditions. Winter torpor lasts approximately seven months with males emerging in early September and spermatogenesis occurring from September–November. Females emerge later, with vitellogenesis occurring from September–December. Gravid females may be found between October and January, but females are non-vitellogenic from late December until the following season. The first clutch is typically laid from October–December, with a variable clutch size (2–11 eggs). Females store sperm and a second clutch may be laid five weeks after the first. Eggs incubated in artificial enclosures at low altitude hatched after 72–106 days, after experiencing an average daily temperature of 19°–22°C, and a range of 5°–39°C.

Key Words: Agamidae, dragon lizard, reproductive ecology, *Rankinia*, Tasmania.

INTRODUCTION

Rankinia diemensis (Gray, 1841) is the only lizard species representative of the Family Agamidae, commonly known as dragon lizards, found in Tasmania; the remaining 17 species comprising Tasmania's lizard fauna are all skinks in the Family Scincidae (Hutchinson *et al.* 2001). It is distinctive among Australian dragons as it is the southernmost agamid in the world and occurs in arguably the coldest habitats occupied by any agamid in Australia (Kent 1987, Hutchinson *et al.* 2001). It is one of only three oviparous reptiles in the State — a strategy in itself that is atypical of cold-climate reptiles (Shine 1985).

Rankinia diemensis is a small cryptic species that exhibits strong female-biased size dimorphism (Cogger 1992). It is widespread throughout all of Tasmania east of Tyler's Line (a faunal divide defined by Shiel *et al.*1989) and occurs also in the Furneaux Group, Flinders Island and nearby islands in Bass Strait, as well as in Victoria and southern New South Wales. On the Australian mainland it is mostly restricted to higher altitudes, giving rise to its common name, the 'mountain dragon' (Kent 1987). This species has frequently been re-classified, but we use genus *Rankinia* because the most recent phylogenetic analyses by Melville *et al.* (2001) place the current status of this species in this monotypic group, rather than including it in the genus *Tympanocryptis*.

Agamids are typically distributed through hot, arid or tropical regions (Greer 1989, Witten 1993) and the cool-cold temperate climates found in Tasmania represent extreme conditions and result in a greatly reduced activity season compared to that of the island's skink fauna. Winter torpor in adult *R. diemensis* lasts for seven months (J.S-S. unpubl. data), significantly longer than that occurring in viviparous alpine skinks (e.g., *Niveoscincus microlepidotus* (O'Shaughnessy, 1874): 5–6 months). This paper provides preliminary data on the reproductive ecology of *R. diemensis*. Our aim is to provide baseline information on a species that has not been studied anywhere in its distribution and that represents an important element of the herpetological fauna of Tasmania.

MATERIALS AND METHODS

This study presents previously unpublished data collected over three breeding seasons (Welling 1999, Duraj 2002); animals were observed *in situ* or collected and held for study in individual outdoor enclosures at the University of Tasmania. The information presented relates predominantly to reproductive ecology but relevant data on morphology and behaviour are also provided.

Lizard collection

Gravid females were caught (while digging nesting burrows) by hand from areas of southeastern Tasmania in October/ November 1998 and 2001 for investigation of reproductive output and strategy. Collections were made from similar habitat (coastal heathland and dry sclerophyll forest) in and around the Cape Deslacs Reserve, Clifton Beach, Kingston township and the University grounds. Individual enclosures were circular (made of sheet metal: diameter 1 m; walls 40 cm high), located on an easterly-facing slope and filled with brown road gravel to a depth ranging from 15–30 cm. Rocks and litter provided cover and vantage points, while a wire netting lid provided protection from predators. The entire set of enclosures was protected under bird netting. Water was provided *ad libitum* and food (ants or mealworms) was provided three times per week.

Nesting Behaviour and Egg Collection

Females preparing to oviposit undertake a period of test burrow-digging that lasts for several days. Once this behaviour was observed captive females were monitored twice daily. Date of test burrows was recorded, as were behaviours associated with actual nest-digging and laying. After oviposition, females were removed, weighed (± 0.1 g) and a range of morphometric characteristics (snout-vent and tail lengths; head width, depth, length; and interlimb and limb measurements) recorded using electronic calipers accurate to ±0.01 mm. Most eggs were carefully uncovered, transferred to the laboratory, weighed using a Sartorius electronic balance (±0.01 g) and used in a series of incubation experiments not reported here.

Natural Egg Incubation

A total of five nests (two in 1999, three in 2002) were randomly selected to remain *in situ* as outdoor enclosure nests. The nests were carefully uncovered so that a temperature logger could be placed adjacent to eggs to automatically record nest temperature every 15 minutes for the duration of the incubation period.

Reproductive Cycles

Gonad development and reproductive status were assessed by dissection of preserved material held in the collections of the Queen Victoria Museum, Launceston, and the Tasmanian Museum and Art Gallery, Hobart (n = 62: 14 adult males, 26 adult females and 22 juveniles). The animals had been collected from areas across Tasmania between 1936 and 1998, and were collected during all months of the activity season.

In males, the testes were measured using electronic digital calipers accurate to ±0.01 mm and testicular volume was calculated from the volume of an ovoid, and the epididymides were inspected for the presence of spermatozoa in the lumen. Subsequently, males were subjectively categorised as active (enlarged testes and milky epididymides), regressed (small testes and dark epididymides), or recrudescent (moderate enlargement of testes, but dark epididymides). Females were dissected (n=26) and classified based on the size and appearance of the follicles and the presence of oviductal eggs. The number of ovarian follicles and their diameter was recorded (using electronic calipers). Animals were categorised as: non-vitellogenic (follicle diameter <1mm), vitellogenic (follicle diameter 1–2 mm), gravid (oviductal eggs present) or recrudescent (vitellogenic follicles >1mm).

RESULTS AND DISCUSSION

Morphology

Rankinia diemensis is a relatively small, cryptic, dragon lizard exhibiting strong female-biased size dimorphism. In Tasmania the largest snout-vent length (SVL) we have recorded for females is 84 mm and for males is 66 mm. Table 1 allows comparison of mass and size of adults of both sexes (also see fig. 1). Sexual size dimorphism is common in Australian agamids; however, in most species males are the larger sex, a characteristic linked to the establishment and defence of territories (Brattstrom 1971). In most agamids, males are aggressive and conspicuous defenders of territories and this forms the basis of mate selection. The existence of female–biased sexual dimorphism and apparent lack of male territories in *R. diemensis* may have significant implications for sexual selection strategies in this species.

Colouration varies from pale beige, through to light and dark greys, bright orange or red-brown (J.S-S. unpubl. data, Hutchinson *et al.* 2001, fig. 1), with mixes of all colours seen in individuals. There does not appear to be sexual dichromatism in this species, which relies heavily on camouflage for avoidance of predators. The colouring reflects this — usually varying according to habitat; it also has modified epidermal scales characteristic of all agamids (Witten 1993), in the form of rough or spiny scales (Hutchinson *et al.* 2001). A distinctive line of dark diamond-shaped marks runs dorsally along the spine from head to tail base — with patches of lighter colour between the 'diamonds' (fig. 1). When the animal is cold, it becomes dark and patterning is obscured (Hutchinson *et al.* 2001). Colour changes also occur in the base colour of individuals (i.e., between the diamonds). These changes can occur relatively quickly (within minutes), and are common among agamids, probably pertaining to social interactions (Greer 2003).

Behaviour

Crypsis

Although *R. diemensis* relies heavily on camouflage to avoid predator detection, it also employs cryptic behaviour, spending most of its time motionless, even to the extent of appearing to regulate breathing. When approached it will typically run a short distance, before stopping abruptly (Hutchinson *et al.* 2001). The sudden stop is unexpected by the observer, and, even though it does not always occur when cover has been reached, it is still an effective form of predator escape because the observer's eye typically follows the direction of

TABLE 1
Comparison of snout-vent length, mass and tail length for adult male and female *Rankinia diemensis*

	Snout-vent length (mm)			Mass (g)			Tail length (mm)		
	Range	Mean	N	Range	Mean	N	Range	Mean	N
Male	49–66	57	24	2.8–6.8	4.6	24	82–113	97	24
Female	56–82	72	34	5.6–13.4	10.3	33	82-137	117	33

FIG. 1 — Dorsal patterning and sexual size dimorphism in Rankinia diemensis *(gravid female top, male below).*

movement beyond the lizard. The camouflage provided by the lizard's outline, colouration and patterning makes the motionless animal very difficult to detect.

Timing of events

Adults may undergo a torpor lasting up to seven months, but hatchlings appear to spend significantly less time in torpor — presumably since they do not have the ability to build sufficient reserves to support such an extended period without food. Field observations reveal that hatchlings remain active well into the autumn months (late April), while adults are rarely seen by late summer (mid-February). Adults have been maintained in laboratory torpor conditions for six months at 5°C — indicating that arousal from torpor to forage is not necessary, but during this time they have been observed drinking water occasionally.

Field observations reveal that males emerge in early spring (early September) at least two weeks before females. They spend considerable time perched on logs or rocks (at heights up to 1 m), which is atypical of their normal cryptic behaviour. It is unclear whether either sex maintains a territory, but there is certainly no obvious territorial behaviour. Females emerge later in spring, and are able to lay a clutch by early summer (November to mid-December). Females prefer relatively open sites to lay their eggs — disturbed soil is often favoured and the sides of quarries and edges of dirt roads are often used as nest sites.

Early in summer, and once the breeding season has finished, both males and females moult. Activity then undergoes one further peak of reduced intensity (late December to mid-January) when second clutching may occur. From this point on, adults are rarely seen. Immature lizards (including hatchlings from the previous year) are active throughout the season. Hatchlings emerge in March/April, and are active as long as the warmer weather lasts. Although hatchlings are commonly sighted, older juveniles are rarely seen at any time. This may be due to high mortality over the first winter season, consequent on the long incubation period and emergence close to the onset of winter, but it may also reflect the extremely cryptic behaviour typical of adults outside the breeding season.

Displays and communication

Communication is primarily visual among *R. diemensis*, as in agamids generally (Greer 1989, Witten 1993, Ord & Evans 2003), but hissing has been heard at capture (J.S-S. unpubl. data.). This behaviour is not unheard of in dragons, although it is rare (Greer 1989). Agamids typically produce discrete visual displays to mediate social behaviour (Watt & Joss 2003), and some of these are utilised by *R. diemensis*, including arm-waving, head-bobbing, and tail lashing. Typically these displays denote aggressive or submissive behaviour. The structure or function of these displays has not been determined for *R. diemensis* and they are the subject of a current study (J. S-S).

Reproduction

Reproductive cycles

Environmental conditions, particularly climatic, can have a strong influence on reproductive cycles. Oviparous lizards are not common in areas of cold, variable conditions because they do not have control over the conditions experienced during egg incubation (Heatwole & Taylor 1987). When seasonal temperatures are highly variable, as in Tasmania's climate, there is only a short summer period for reproduction, embryonic development and offspring dispersal to occur. Examination of museum specimens indicated that spermatogenesis occurs from early September to early November (n=15) with testes size reaching a maximum in late September. Testes have regressed to one quarter of their maximum volume by late October, and remained regressed thereafter until late February. Recrudescence begins in March (fig. 2). Late October to early November appears to be the main mating period, during which time males store sperm in their epididymides.

Females emerge from winter torpor later than males (late September), with vitellogenesis occurring from September–December, and gravid females recorded from late October to January. Females are non-vitellogenic from late December to March, when recrudescence begins (fig. 2).

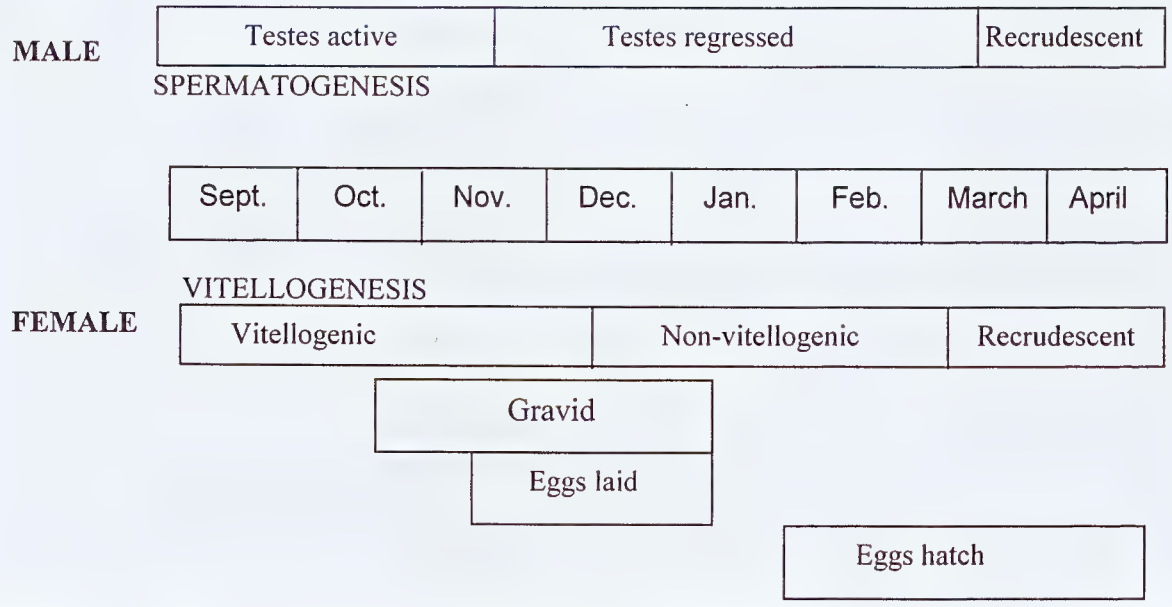

FIG. 2 — Calendar of major reproductive events in males (top) and females (below) of Rankinia diemensis.

Nesting behaviour and oviposition

Females produce first clutches between October and December in Tasmania. Gravid females usually excavate a series of 'test' burrows prior to digging the final nest; these are more shallow than the final nest, and remain uncovered. Females maintained in artificial outdoor enclosures (n=23) averaged two test burrows prior to oviposition, and the average time between the first test burrow and oviposition was five days. Test burrows surrounding natural nests (verified by uncovering nests) have also been observed in the wild, and on three occasions burrows have been filled in on a different day than that on which they were excavated. Test burrows are often quite close to the final nest site, and females have been observed digging burrows within 1.5 m of each other, at the same time, and in full view of each other. Observations of extensive 'tongue-flicking' (in enclosures) prior to oviposition suggest that chemical cues may be an important determinant in nest site selection. Nests are usually located in relatively open areas — with no direct shading, but still in close proximity to some form of cover.

Final burrow excavation and ovipositing takes most of a day and, if started late, may spill over to a second day. Before starting, females exhibit heightened alertness for as long as two hours, usually perched on a vantage point about 30 cm above ground at the edge of an open patch. Digging involves excavating soil with the forelimbs and flicking it backwards with the larger hind limbs. Digging takes place at an angle, creating a burrow 60–85 mm deep (n=23). During laying, the female reverses her position so that her head and forelimbs protrude from the nest, as does her tail (bent around to one side). When laying is finished she exits from the burrow, and may turn and move the eggs about with her snout before covering them. Digging and oviposition takes several hours. When finished the female covers the eggs by flicking soil back into the nest with her fore- and hind- limbs, with intermittent bouts of rapid fore-limb stamping and snout-pushing of the soil covering the eggs, presumably to compact it. She may spend as much as two hours on this activity; once completed it is impossible to locate the nest visually.

Clutch characteristics

Clutch size varies from 2–11 eggs, with female size being positively correlated with clutch size. Egg mass at oviposition is between 0.4 and 1.0 g (for eggs that hatch successfully), with dimensions averaging 110 x 70 mm (see table 2 for egg measurements). A second clutch can be produced five weeks after the first, but almost invariably this will contain fewer eggs than the first. Reduced clutch size later in the season is typical of lizards that produce multiple clutches in a single breeding season (Nussbaum 1981, Forsman 2001). James & Whitford (1994) concluded that progressively smaller clutches in the side-blotched iguanid *Uta stansburiana* (Baird & Girard, 1852) was an adaptive response to poor environmental conditions that occur late in the season; they argued that smaller clutches lower the risk of reproductive failure for the female. Similarly for *R. diemensis*, environmental conditions deteriorate later in the season, with cooler temperatures, reduced photoperiod, and often increases in rainfall. In *R. diemensis*, however, individual eggs in the second clutch are larger, indicating that, although fewer eggs are being produced, more energy is being allocated to each egg. Presumably this

TABLE 2
Reproductive investment and egg dimensions at oviposition

	Mean (± s.e.[1])	Range
Relative clutch mass[2] (%)	45 (2)	0.16–0.71
Clutch size	6.0	2–11
Clutch mass (g)	4.52 (0.23)	1.82–7.01
Egg mass (g)	0.69 (0.01)	0.43–1.01
Egg length (mm)	11.0 (0.07)	7.0–14.5
Egg width (mm)	7.0 (0.05)	5.0–8.0

[1] s.e. = standard error))

[2] Relative clutch mass = (mass of eggs/(mass of female – mass of eggs))*100

provides more energy for development if this is prolonged by poor incubation conditions and/or larger hatchlings with a greater chance of survival when emergence occurs very late in the season. Size at emergence has significant consequences for a hatchling's subsequent growth, survival (Sinervo 1993), and ability to forage effectively and escape predators (Phillips *et al.*1990).

Females held in captivity from early spring, without access to males, are able to lay a second clutch, clearly demonstrating their ability to store sperm. Among Australian agamids this has only been demonstrated for one other species: the bearded dragon, *Pogona barbata* (Cuvier, 1829) (Amey & Whittier 2000), though it may be quite common. The advantages associated with sperm storage include improving opportunities for sperm competition between sperm from different males (Parker 1970) (assuming that females mate with more than one male). It may also reduce competition between the sexes for resources, thus facilitating production of a second clutch, and it also ensures that reproduction is still possible if the potential of encountering males is low (Kumari 1990) or if male activity decreases later in the season.

Incubation

Incubation duration ranged from 72–106 days in enclosure nests with a hatching success of ≥80%; duration strongly depended on the temperatures experienced during incubation. Warmer nest temperatures have strong implications for hatchling survival as they result in shorter incubation times, meaning longer foraging and basking times prior to the first winter torpor (Gutzke & Packard 1987, Packard & Packard 1988).

Data from temperature loggers in the five nests located in our outdoor enclosures revealed that eggs experienced average daily temperatures of between 19° and 22°C, although the range was from 5°–39.5°C. As expected, clutches that spent a greater amount of time at lower temperatures, had longer incubation durations. Since the period available to hatchlings for foraging prior to winter is limited, earlier emergence, from nests located in warmer incubation sites will provide more time for basking and foraging. Maternal nest site choice may therefore be a key determinant of a female's reproductive success. Unlike many other agamids, temperature-related sex determination does not occur in *R. diemensis* (J.S-S. unpubl. data).

CONCLUSIONS

Rankinia diemensis is a relatively small cryptic dragon lizard, although Tasmanian specimens reach a larger size than their mainland counterparts (Cogger 1992). In Tasmania, and probably elsewhere, its life history strategy is constrained by climate, which necessitates spending much of its time in torpor, severely reducing the time available for reproduction and growth. Egg incubation periods are long, due to cool nest temperatures, and hatchling survival is endangered by the short period of time prior to winter in which fat reserves are built. The species presents an ideal opportunity for examining the evolution and adaptation to cool climates of life history in oviparous lizards. Although we have provided the first extensive data on the reproductive ecology of the mountain dragon in Tasmania, many questions remain. Regarding reproduction, the existence of pronounced female-biased size dimorphism, very unusual for agamid lizards, raises intriguing questions about sexual selection strategies and their responses to climatic constraints. Likewise, an understanding of how conditions during and immediately following torpor influence survival and reproductive investment would yield valuable insight into how this unusual dragon maintains successful populations even on the exposed Central Plateau of Tasmania.

TABLE 3
Duration of incubation and nest temperatures in five nests located in artificial enclosures

Duration of incubation (days)	Nest temperature	
	Mean (±s.e.)	Range
72	19.7 (0.09)	5.6–38.1
78	20.3 (0.09)	8–39
99	21.1 (0.10)	10.3–38.1
106	17.3 (0.06)	8–37.5
106	17.7 (0.12)	6–39.5

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SEASONAL ACTIVITY PATTERNS OF THE FROG, *CRINIA SIGNIFERA* (ANURA: MYOBATRACHIDAE), IN SOUTHERN TASMANIA, AUSTRALIA

by Bonnie Lauck, Roy Swain and Richard Bashford

(with one text-figure)

Lauck, B., Swain, R. & Bashford, R. 2005 (16:xii): Seasonal activity patterns of the frog, *Crinia signifera* (Anura: Myobatrachidae), in southern Tasmania, Australia. *Papers and Proceedings of the Royal Society of Tasmania* 139: 29–32. ISSN 0080–4703. School of Zoology, University of Tasmania, GPO Box 252-05, Hobart, Tasmania 7001, Australia (BL,* RS); Forest Entomology, Forestry Tasmania, 79 Melville Street, Hobart, Tasmania, 7000, Australia (DB). *Author for correspondence.

We investigated the seasonal adaptations of the myobatrachid frog *Crinia signifera* Girard, 1863 in a commercial forest in southern Tasmania, Australia. Seasonal variation in activity patterns, body size and body condition was investigated. Although *C. signifera* does not hibernate over winter, activity levels are much reduced during this time. Females trapped in summer were smaller than those captured throughout the remainder of the year. We interpreted seasonal variation in the condition of captured frogs as an indication that breeding in spring and early summer is metabolically costly and fat stores are replenished by extensive foraging in summer. Fat stores accumulated in summer and autumn by males are used for body maintenance over winter and breeding in the following spring.

Key Words: body condition, *Crinia signifera*, frog, seasonal variation, Tasmania, activity.

INTRODUCTION

Anurans are ectothermic and their body temperatures are strongly correlated with ambient environmental temperatures. They also have a moist, permeable skin and are susceptible to desiccation (Blaustein *et al.* 1994). A trade-off between body temperature and water balance (Navas 1996) means that amphibian activity is often regulated by a combination of temperature and rainfall (Lemckert 2001). For example, the degree and duration of activity of the wood frog (*Rana sylvatica* LeConte, 1825) decreased with decreasing humidity (Bellis 1962).

With these physiological constraints, it is logical that seasonal environmental changes may regulate the activity patterns of amphibians. Variations in ambient temperature may also affect metabolism, thus affecting both body size and body condition. Ryser (1989), for example, concluded that weight loss in *Rana temporaria* Linnaeus, 1758 is caused by elevated metabolism. Reading & Clarke (1995) found that, in addition to toad density at the breeding site, body condition of *Bufo bufo* (Linnaeus, 1758) was significantly correlated with air temperature.

Most studies investigating seasonal variation in activity, body size and body condition of temperate climate anurans have been carried out in the Northern Hemisphere (for example, Lamoureux *et al.* 2002, Morton 1981, Reading & Clarke 1995). These studies have identified a general pattern in which migration to a breeding site occurs in spring and energy stores are rapidly depleted as a result of breeding. Fat storage is then replenished by a period of foraging activity and body condition is generally at its greatest at the end of autumn. These energy stores are then used during hibernation and the first few weeks of activity in the following spring.

Studies investigating seasonal variation in activity are carried out usually by trapping at breeding sites. As a consequence, studies that include the non-breeding fraction of the population are rare. Little is known also about the seasonal variation in activity of Australian amphibian populations. We investigated both this and the seasonal variations in body size, body condition and sex ratio in the anuran *Crinia signifera* in order to gain a greater biological understanding of the species at the southern limits of its latitudinal range in southern Tasmania, Australia.

METHODOLOGY

Study Species

Crinia signifera is widely distributed throughout Tasmania and south-eastern mainland Australia and is found in a wide range of habitats (Robinson 1996). This species breeds in both permanent and ephemeral sites; and in Tasmania breeding is limited to lentic systems (Littlejohn 2003, BL unpubl. data). In the southern forests of Tasmania breeding occurs predominantly between early spring and mid-summer with autumn breeding less common (BL unpubl. data). Metamorphosis occurs predominantly in January and February (BL unpubl. data).

Study Area

The study area is located at the Warra Long Term Ecological Research (LTER) site within the southern production forests of Tasmania. The site (43°3'S; 146°39'E) is approximately 60 km south of Hobart with an elevation range of 37–1260 m (Brown *et al.* 2001). Average annual temperature and rainfall are 7.9°C and 1477 mm respectively. Monthly variation in temperature is significant with mean diurnal temperatures of less than 4°C in winter and approximately 12°C in summer (www.warra.com 2005). Rain falls throughout the year but average monthly rainfall shows a strong winter bias and is at its lowest in late summer (Ringrose *et al.* 2001).

Trials were established at the Warra LTER to investigate alternative silvicultural practices (Hickey *et al.* 2001). One investigative sub-component of these silvicultural trials is to

measure the responses of invertebrates. The specimens of *C. signifera* that we used in this study were opportunistically obtained as a by-catch from wet pitfall-traps used in this invertebrate study (see Bashford *et al.* 2001).

The following sampling strategy is summarised from Bashford *et al.* (2001). Twenty sites (located within five logging coupes) had been established at the site. Each site consisted of a 50 m transect with 10 pitfall traps. Pitfall traps were arranged in pairs, each separated by 1–2 m, and consisted of a 9 cm-diameter, 15 cm-long PVC stormwater pipe set vertically into an augered hole in the soil. A 425 mL plastic cup (diameter = 9 cm, 'Cast Away' brand) was set inside each pipe. Each cup was charged with 100 mL of either 33% ethylene glycol (Castrol RadiCool) or 100% ethylene glycol (Castrol). For further details regarding the construction of pitfall traps refer to Bashford *et al.* (2001).

Sampling took place between September 1997 and December 2002. Trapping was undertaken in all seasons, with the number of trapping days totalling 2187 in summer, 982 in autumn, 331 in winter and 1064 in spring. Because sampling effort was unequal in different seasons and at different sites, captures were converted to capture rates (captures per trap day) in order to enable comparisons to be made.

Trapped frogs were killed and preserved by the ethylene glycol, and specimens were stored in 70% ethanol after field collection. Each specimen was patted dry with paper towelling before its mass was measured using an electronic balance (± 0.005 mg), and its snout-vent length (SVL) was measured using callipers (± 0.05 mm). The sex of adults was determined by morphological characteristics (males have grey, and females have white, colouring on the ventral surface of the chin). Individuals were classed as juveniles if the SVL was less than 20 mm (refer to growth curves in Lauck 2005). Because immature frogs of either sex also have grey ventral chin colouring (BL unpubl. data), juveniles were dissected to determine sex. Body condition was calculated as the cubed root of body mass x SVL^{-1} ($\sqrt[3]{}$ g/mm, pers. comm. R. Alford).

Statistical analysis was undertaken using SPSS™ 10.0 for Windows and α was set as 0.05.

RESULTS

Fifty-two males and 71 females were captured. In addition there were 65 juveniles (including 28 that were too small for sex to be determined). The mean (± SD) of SVL of females, males and juveniles was 26 ± 3.9 mm, 23 ± 2.4 mm and 15 ± 3.0 mm, respectively. The mean mass (± SD) of females, males and juveniles was 2.2 ± 1.00 g, 1.4 ± 0.50 g and 0.4 ± 0.02 g, respectively.

Seasonal captures rates (fig. 1) indicate that frogs were most active within the forest litter during summer and least active during winter. Juveniles were most abundant in the landscape in summer. In winter, females were three times more likely to be trapped than males.

Because juveniles were given an arbitrary classification of having a SVL < 20 mm, seasonal comparison of body size was not valid. One-way ANOVA showed that SVL did not vary with year of capture for females ($F_{4,61}$ = 1.588, P = 0.190). Data from all years were pooled for females, and a one-way ANOVA was used to test the effect of season on SVL. SVL of females was lower in summer (mean and SEM: 25.82 ± 0.546 mm) than in autumn (26.59 ± 1.109 mm), winter (30.55 ± 1.281 mm) and spring (27.86 ± 0.810 mm; $F_{3,61}$ = 4.510, P = 0.007). Because the SVL of the males differed with the year of capture ($F_{4,39}$ = 4.721, P = 0.005), a two-way ANOVA examining the effect of season and year was used to test the seasonal variation of SVL. SVL of the males did not differ with the season of capture ($F_{3,39}$ = 0.654, P = 0.588). There was no significant interaction between year and season ($F_{5,39}$ = 1.321, P = 0.285).

Body condition could not be calculated for females because clutch mass was not measured separately from remaining body mass. One-way ANOVA showed that body condition did not vary with year of capture for both males and juveniles ($F_{4,38}$ = 1.692, P = 0.175 and $F_{5,55}$ = 1.846, P = 0.121, respectively). Data from all years were pooled and

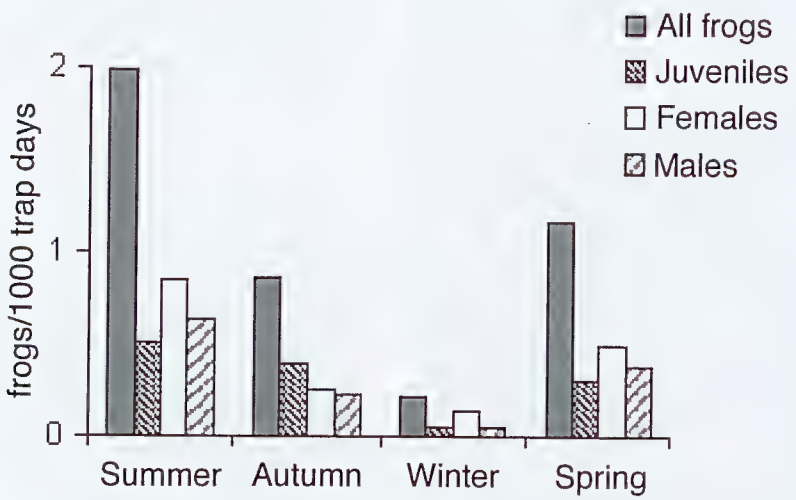

FIG. 1 — Seasonal variation in Crinia signifera *capture rates (frogs per 1000 trap days) for all frogs, juveniles, females and males.*

a one-way ANOVA was used to test the effect of season on body condition. Body condition of adult males differed significantly between seasons ($F_{3,38} = 3.542$, $P = 0.024$). Body condition was greatest in winter (mean and SEM: 0.45 ± 0.024), followed by spring (0.41 ± 0.011), autumn (0.39 ± .013) and summer (0.38 ± 0.008). Juvenile body condition did not vary with season ($F_{3,55} = 0.72$, $P = 0.544$).

DISCUSSION

Most previous studies investigating seasonal adaptations of amphibians have been carried out by trapping at breeding sites over a number of breeding seasons (for example Mac Nally 1981, Reading & Clarke 1995, Williamson & Bull 1999). Studies incorporating the component of the population that is not actively involved in breeding are not common in the literature. Our study provides a rare opportunity to investigate just such an extended population of *C. signifera* in the southernmost part of its range in Tasmania, Australia.

Although higher capture rates of both males and females occurred during the summer it is interesting to note that females trapped in summer were smaller than in other seasons. It is likely that these individuals represent younger females that have a greater tendency to abstain from breeding and to maximise foraging in order to divert energy to further growth rather than reproduction (Lauck 2005). Such a trade-off between current reproduction and future reproductive success occurs because increased body size is often correlated with increased clutch size in female amphibians (Berven 1982, Lemckert & Shine 1993, Ponsero & Joly 1998).

Juveniles were also most commonly captured in summer, coinciding with the peak period of metamorphosis (BL unpubl. data). Although fewer juveniles were captured in other seasons in Tasmania, their body condition did not differ from those captured in summer.

Male body condition was at its greatest in winter, indicating that a preceding period of extended foraging had occurred. Unlike many anuran species of the Northern Hemisphere (Morton 1981, Reading & Clarke 1995), *C. signifera* does not appear to hibernate over the winter, although activity levels are much reduced in comparison to other seasons. Depleted body condition in spring indicates that reduced activity in winter did not allow sufficient foraging to sustain male energy stores.

That breeding is metabolically costly is indicated by male body condition which was at its lowest in summer after the extended calling period. Lemckert & Shine (1993) and Mac Nally (1981) also found that males of *C. signifera* lost significant energy reserves during periods of extended calling, despite the fact that it was possible for them to forage during this time.

The seasonal activity patterns of *C. signifera* in Tasmania show similar trends to those observed for other Northern Hemisphere temperate frogs. Our findings also concur well with those of other studies investigating the costs of reproduction in *C. signifera* breeding populations on mainland Australia.

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CONTRIBUTIONS TO A CATALOGUE OF ALIEN PLANTS IN TASMANIA I

by Matthew L. Baker

(with seven plates and 11 text-figures)

Baker, M.L. 2005 (16:xii) Contributions to a catalogue of alien plants in Tasmania I. *Papers and Proceedings of the Royal Society of Tasmania* 139: 33–48. ISSN 0080–4703. Tasmanian Herbarium, Tasmanian Museum and Art Gallery, Private Bag 4, Hobart, Tasmania 7001, Australia.

The status of 11 alien plant taxa recorded in Tasmania is discussed. *Hypericum humifusum* L. and *Solanum americanum* Mill. have been recorded only once and further evidence is required to determine their status in Tasmania. *Setaria pumila* (Poir.) Roem. & Schult. subsp. *pumila* is a recent incursion of an Australian mainland weed that has been recorded once in Tasmania and has since been eradicated from the recorded site. A treatment of naturalised *Cotoneaster* Medik. in Tasmania is included. *Genista linifolia* L. and *Kunzea ericoides* (A.Rich.) Joy Thomps. are ornamental taxa that are naturalised in Tasmania. Tasmanian specimens of *Plantago coronopus* L. are treated at subspecific rank: *P. coronopus* subsp. *coronopus* and *P. coronopus* subsp. *commutata* (Guss.) Pilg. A diagnostic description for each taxon is provided and distribution and habitat details are discussed. Keys to the Tasmanian species of *Cotoneaster*, *Genista* L., *Kunzea* Rchb. and *Setaria* P. Beauv., and to the subsp. of *Plantago coronopus* are included.

Key Words: naturalised, incursions, exotic, weeds, introduced, flora.

INTRODUCTION

Alien species comprise a considerable proportion of Tasmania's plant biodiversity. The most recent catalogue of Tasmanian vascular plants (Buchanan 2004) lists 774 plant taxa at specific and subspecific rank as being naturalised or 'sparingly naturalised'. This equates to nearly 30% of the total vascular plant flora of Tasmania.

Much of the literature pertaining to naturalised plant incursions in Tasmania has been summarised by Rozefelds *et al.* (1999) and Rozefelds & McKenzie (1999). Although outdated, particularly with respect to the alien flora, *The Student's Flora of Tasmania* (Curtis 1963, 1967; Curtis & Morris 1975, 1994) remains the most comprehensive account of the naturalised plants in Tasmania. Several handbooks that deal specifically with weeds that occur in Tasmania have also been produced (e.g., Hyde-Wyatt & Morris 1975, 1980). Tasmanian distributions for certain alien species are also cited in broader focus volumes dealing with Australia as a whole (e.g., Auld & Medd 1987, Lazarides *et al.* 1997, Parsons & Cuthbertson 2001), in various state floras (Harden 1992, 1993, 2000, 2002; Walsh & Entwisle 1994,1996,1999) and in the *Flora of Australia* series.

The number of naturalised plants in Tasmania has been increasing rapidly since the earliest days of settlement. The earliest catalogues of plant naturalisations in Tasmania were made by Spicer (1878a, 1878b). Rozefelds & McKenzie's (1999) appraisal of Spicer's publications indicates that by the 1870s, 104 alien plants had become naturalised in Tasmania. A review of more recent statistics of alien invasions in Tasmania was compiled by Rozefelds *et al.* (1999). This research showed that between 1971 and 1995, 159 plant taxa had been recorded as naturalised, bringing the total number to over 740 naturalised taxa. In the period between Rozefelds *et al.* (1999) and the latest edition of the Tasmanian vascular plant census (Buchanan 2004), an additional 34 alien plant taxa are recorded. Thus the number of naturalised plants in Tasmania is clearly not stable and is generally increasing at a steady rate.

Changes to the number of alien plants listed as naturalised or 'sparingly naturalised' in Tasmania occur by numerous methods. There are incursions of new alien species, new records as the identity of plants that may have been in Tasmania for some time is recognised, and new names as advances in taxonomic work occur. There are even examples of alien plants that are believed to have been eradicated from the state or that may have become locally extinct.

Management of Tasmania's alien flora requires an accurate and up-to-date account of taxa present. It is envisaged that this paper will be the first part of a series aiming to ensure that taxa which become naturalised in Tasmania are formally recorded; that taxa that are present in Tasmania, but have not become fully naturalised, are likewise recorded; that new incursions of alien taxa are recorded; and to maintain up-to-date names for taxa that have been affected by nomenclatural change. In this paper, 11 taxa are treated, giving diagnostic descriptions and notes on distribution. It is hoped that this information will increase general knowledge of distribution of naturalised alien taxa in Tasmania and raise community awareness of plants that have the potential to become naturalised.

MATERIALS AND METHODS

Primary sources used for this study are specimens held in the Tasmanian Herbarium (HO). Herbarium abbreviations follow Holmgren *et al.* (1990). Identifications by the author and others were checked against literature and, where available, reliably identified voucher specimens.

Voucher specimens for all species treated have been lodged with the Tasmanian Herbarium. The naturalised status of treated species is based upon field observations made by the author and others and, when available, from notes accompanying specimens.

Citations of synonyms are limited to names used in Tasmanian literature. Tasmanian distributions follow floristic regions proposed by Orchard (1988). Geographical origins of plants treated have been determined from various published sources.

DEFINITIONS

The status of a species, that is, whether it is naturalised or not, may be subjective and not always clearly definable. However, for the most part, the following definitions from Pyšek *et al.* (2004) of an alien plant and a naturalised plant have been adopted.

Alien refers to 'plant taxa in a given area whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien'.

Naturalised refers to 'alien plants that sustain self-replacing populations for at least 10 years without direct intervention by people (or in spite of human intervention) by recruitment from seed or ramets (tillers, tubers, bulbs, fragments, etc.) capable of independent growth'. This period of time for a plant's persistence to deem it naturalised was chosen by Pyšek *et al.* (2004), as it takes into account the possible negative effects of short-term 'catastrophic events' such as climatic extremes and outbreaks of pests and pathogens that may impact on a species' existence. For some species early records indicate that a plant's persistence may be less than 10 years and therefore they do not meet the above definition of being naturalised. In these cases a plant's invasiveness, estimated age at time of collection and other observations may justify it being regarded as naturalised.

'Sparingly naturalised', the term used in the Tasmanian vascular plant census (Buchanan 2004), covers those species that do not meet the definition of being naturalised, but are showing signs that they may do so in the future. In essence, the next wave of naturalised plants is likely to come from these species. It is crucial to document these species for weed management purposes.

The status of an individual species in Tasmania should be based upon an assessment of the plant's lifecycle, the size of the population, the species' status in other similar areas and site history.

NATURALISED TAXA IN TASMANIA

1. *Cotoneaster* Medik. *Philos. Bot.* 1: 154 (1789). (Rosaceae)

Description: Evergreen, semi-evergreen or deciduous shrubs or small trees; branches without spines or prickles, often pubescent especially when young. Leaves simple, alternate, entire, petiolate, stipulate. Flowers terminal or axillary, solitary or in many flowered cymes; sepals 5; petals 5, erect or spreading, white, pink or occasionally red; stamens 10–20(–22); ovary inferior or semi-inferior, carpels 2–5. Fruit a pome, red to black (not in Tas.), with 2–5 pyrenes (seeds).

For a comprehensive description see Lu & Brach (2003).

Discussion: *Cotoneaster* is a genus of c. 260 species (Phipps *et al.* 1990), found mainly in temperate north Africa, Asia, central America and Europe, but most abundant in south-west China (Lu & Brach 2003). Several species of *Cotoneaster* have been introduced to Tasmania as garden plants because of their hardiness and striking display of colourful berries during autumn and winter months. Several species have spread from cultivation and become naturalised, most commonly spread by bird-dispersed seed. Buchanan (2004) indicates that four alien species, *C. glaucophyllus* Franch., *C. franchetii* Bois, *C. pannosus* Franch. and *C. simonsii* Baker, are naturalised in Tasmania. Until now there has been no taxonomic account of *Cotoneaster* in Tasmania.

The species of naturalised *Cotoneaster* can be identified using the following key and descriptions. The fruiting branches of the naturalised species are illustrated in pl.1.

Key to the species of *Cotoneaster* in Tasmania

1. Inflorescence more than 20-flowered; petals white and spreading; leaves usually more than 30 mm long ... ***C. glaucophyllus***
1: Inflorescence less than 20-flowered; petals white or pink; leaves usually less than 30 mm long 2
2. Leaves elliptic, rhombic or ovate, sparsely hairy on lower surface, with the lamina visible between the hairs; fruit with 3–4 pyrenes ..... ***C. simonsii***
2: Leaves elliptic or ovate, persistently densely hairy on lower surface, with the lamina obscured by the hairs; fruit with 2–3 pyrenes 3
3. Leaves usually less than 30 mm long, with veins on upper surface inconspicuous; petioles 4–8 mm long; petals white, spreading; fruit with 2 pyrenes..... ***C. pannosus***
3: Leaves usually 20–35 mm long, with veins on upper surface conspicuous; petioles 3–4 mm long; petals white to pinkish, erect; fruit with 2–3 pyrenes ***C. franchetii***

1a. *Cotoneaster glaucophyllus* (Franch.) var. *serotinus* (Hutch.) L.T.Lu & Brach, *Novon*, 12(4): 495 (2002). (Rosaceae)

Illustration: Jeanes & Jobson (1996, p. 579, fig. 118d-e); pl. 1B.

Description: Semi-evergreen shrubs 2–5 m tall. Young stems pubescent, becoming glabrous with age. Leaves (20–)30–60(–80) mm long, 15–25(–40) mm wide, elliptic to ovate, glabrous above, densely hairy below, becoming glabrescent; petiole 5–7 mm long; apex acute to apiculate. Flowers in corymbs, to more than 50-flowered; sepals 1–2 mm long, triangular; petals spreading, 2–3 mm long, orbicular, white. Fruit 4–8 mm long, obovoid, red, with 2 pyrenes.

For a comprehensive description see Lu & Brach (2003).

Discussion: All Tasmanian material can be referred to var. *serotinus*. This taxon was first recognised as a weed in Tasmania in 1987. It is most easily distinguished from the other naturalised species by its relatively large leaves and by the number of flowers that are up to and exceeding 50 per inflorescence.

Distribution and habitat: *Cotoneaster glaucophyllus* var. *serotinus* is native to China where it inhabits mountain regions of the western Yunnan province at altitudes between 1900–3000 m (Lu & Brach 2003). The species is naturalised in New Zealand where it is recorded as a weed of wasteland, scrub in gullies and in gardens (Sykes & Given 1988). In Australia, the species is naturalised in New South Wales (Harden & Rodd 2000), South Australia (Barker *et al.* 2005) and Western Australia (Western Australian Herbarium 1998–). The variety is naturalised in Victoria (Ross & Walsh 2003). In Tasmania, it is recorded as a weed in the East Coast, West Coast and North-West regions (fig. 1). It is associated with disturbed habitats including weedy river banks, roadsides and an abandoned tip site, as well as being found in native vegetation communities adjacent to residential areas. It is commonly grown as an ornamental throughout the state. It is presumed to be more widespread than herbarium records indicate.

First record: 1987, A.M. Buchanan.

Specimens examined: **TASMANIA**: *East Coast region*: Tasmanian Museum & Art Gallery, courtyard of Private Secretary, 4 Jan. 1995, A.M. Buchanan 13837 (HO). Cleburne Point, Risdon Cove, 20 May 1996, A.M. Buchanan 14161 (HO). College Road, opposite Tasmanian Herbarium, University of Tasmania, Sandy Bay, 10 Jun. 1988, A.M. Buchanan 11024 (HO). Old tip site near Proctors Saddle, Hobart, 8 May 1987, A.M. Buchanan 10239 (HO). Sandy Bay Rivulet, upstream from Regent Street, 17 Apr. 2003, M. Baker 98 (HO). *West Coast region*: Outskirts of Tullah on Rosebery side, 18 Jan. 1999, D.E. Symon 15948, (HO, AD, CANB). Queen River. South Queenstown, 50 m E of bridge leading to cemetery, 14 Sep. 2004, M. Baker 496 (HO). Queenstown, park section of Esplanade. Queen River, 100 m S of Penghana Road bridge, 16 Sep. 2004, M. Baker 655 (HO). *North-West region*: Railton on road B13 from Spreyton, 14 Jan. 1999, D.E. Symon 15934, (HO, AD).

1b. *Cotoneaster pannosus* Franch. *Pl. Delavey.* 223 (1890). (Rosaceae)

Illustration: Jeanes & Jobson (1996, p. 579, fig. 118f); pl. 1A.

Description: Semi-evergreen shrub to 2 m tall. Young stems densely pubescent, soon becoming glabrous with age. Leaves 20–30(–38) mm long, 10–15(–17) mm wide, elliptic, glabrous above with veins inconspicuous, densely felty hairy below, with the lamina obscured by the indumentum; petiole 4–8 mm long; apex acute to apiculate. Flowers 6–20 in corymbs; sepals triangular; petals spreading, 3–4 mm long, suborbicular, white. Fruit 5–8 mm long, ovoid, dull red, with 2 pyrenes.

For a comprehensive description see Lu & Brach (2003).

Discussion: *Cotoneaster pannosus* was first recognised as present in Tasmania in 1988. Notes accompanying the collections lack population details or information indicating the species' naturalised status. Without fruit or flowering material, *C. pannosus* could be confused with *C. franchetii*. Characters discussed in the key above, such as petiole length and the relative conspicuousness of veins on the upper leaf surface, may not be sufficient to accurately identify specimens to species.

Distribution and habitat: *C. pannosus* is native to China where it is found in thickets, rocky places and wasteland in mountain slopes at altitudes between 1100–3200 m (Lu & Brach 2003). It is naturalised in New Zealand (Sykes & Given 1988) and has been observed establishing in the vicinity of planted specimens (Heenan *et al.* 1999) as well as in mixed age populations in the grounds of a disused school (Heenan *et al.* 2002). In Australia, it is naturalised in New South Wales, Australian Capital Territory, Victoria (Jeanes & Jobson 1996), South Australia (Barker *et al.* 2005) and Western Australia (Western Australian Herbarium 1998–). In Victoria, it is usually naturalised in cooler regions, near gardens (Jeanes & Jobson 1996). In Tasmania, it is known from two collections, one from a roadside adjacent to a wet gully in the East Coast region and the other from a streambank shrubbery in the North-East region (fig. 2).

First record: 1988, A.M. Buchanan.

Specimens examined: **TASMANIA**: *North-East region*: Symons Creek, Dilston, 1 Jun. 1995, A.M. Buchanan 13867 (HO). *East Coast region*: College Road, opposite Tasmanian Herbarium, University of Tasmania, Sandy Bay, 10 Jun. 1988, A.M. Buchanan 11023 (HO).

1c. *Cotoneaster franchetii* Bois, *Rev. Hort.* 1902: 379 (1902). (Rosaceae)

Illustration: Jeanes & Jobson (1996, p. 579, fig. 118g); pl. 1D.

Description: Semi-evergreen shrub to 3 m tall. Young stems densely pubescent, soon becoming glabrous with age. Leaves (15–)20–35(–40) mm long, 7–15(–20) mm wide, elliptic to ovate, sparsely hairy above with veins conspicuous, densely felty hairy below, with the lamina obscured by the indumentum; petiole 3–4 mm long; apex acute to apiculate. Flowers 5–14 in corymbs; sepals 1–1.5 mm long, triangular; petals 3.5–4 mm long, erect, obovate or elliptic, pink. Fruit 5–10 mm long, obovoid to subglobose, bright red to orange red, with 2–3 pyrenes.

For a comprehensive description see Lu & Brach (2003).

Discussion: *Cotoneaster franchetii* was first recognised as occurring in Tasmania in 1985. Without fruit or flowering material, *C. franchetii* could be confused with *C. pannosus*. Characters discussed in the key above, such as petiole length and the relative conspicuousness of veins on the upper leaf surface, may not be sufficient to accurately identify specimens to species.

Distribution and habitat: *C. franchetii* is native to China where it forms thickets in rocky, sunny mountain regions and open hillsides at altitudes between 1600–2900 m (Lu & Brach 2003). It is naturalised in New Zealand where it has been recorded as a weed of roadsides, scrub, streambanks and forest margins (Sykes & Given 1988). In Australia, it is naturalised in New South Wales (Harden & Rodd 2000) and Victoria (Jeanes & Jobson 1996). In Tasmania, it has been recorded as a weed in the East Coast, North-East, North-West, South-West and West Coast regions (fig. 3). It has been collected from a wide range of habitats including dry coastal bushland, dry sandy slopes bordering saltmarsh, along the banks of the Huon River and in numerous disturbed roadside sites across the state. Based on herbarium records, it is more widespread and common than the similar-looking species, *C. pannosus*. Further surveys would be useful to study their distribution within Tasmania.

First record: 1985, K. Harris.

Specimens examined: **TASMANIA**: *East Coast region*: Pittwater Road, 15 Apr. 1996, A.M. Buchanan 14130 (HO). Tessellated Pavement, Forestier Peninsula, at the stairs leading down to the pavement, 11 Jan. 1999, D.E. Symon 15919, (HO, AD). Channel Highway (B68) 250 m NW of Shot Tower, 3 May 2000, A.M. Gray 1046 (HO). Bush near Hurst Point, Coningham Road, Coningham, 20 Apr. 2003, M. Baker 428 (HO). Lymington Road, Cygnet, 10 Jul. 2003, M. Baker 135 (HO). *North-East region*: Parkside, St Helens, 16 Apr. 1990, A.M. Buchanan 11774 (HO). West Tamar Highway, N of junction with Batman Highway 3 Jun. 1997, A.C. Rozefelds 534 (HO). *South-West region*: Beside N bank of Huon River at Judbury, 13 Jan. 1985, K. Harris (HO). Huon River at Judbury, 2 Apr. 1988, A.M. Buchanan 10896 (HO). *West Coast region*: Outskirts of Strahan on road to Ocean Beach, 20 Jan. 1999, D.E. Symon 15951, (HO, AD). Outskirts of Queenstown on road from Strahan just after turn off to Strahan and by Queenstown Civil Construction Depot, 20 Jan. 1999, D.E. Symon 15956, (HO, AD). Outskirts of Tullah on Rosebery side, 18 Jan. 1999, D.E. Symon 15947, (HO, AD, CANB). Alongside Jones Street, Strahan, 16 Jan. 1998, J.R. Hosking 1558 (HO, AD, CANB, MEL, NE, NSW). Queenstown private garden, Sep. 1978, S.J. Berrigan 134 (HO). *North-West region*: Outskirts, E end of Sisters Beach,

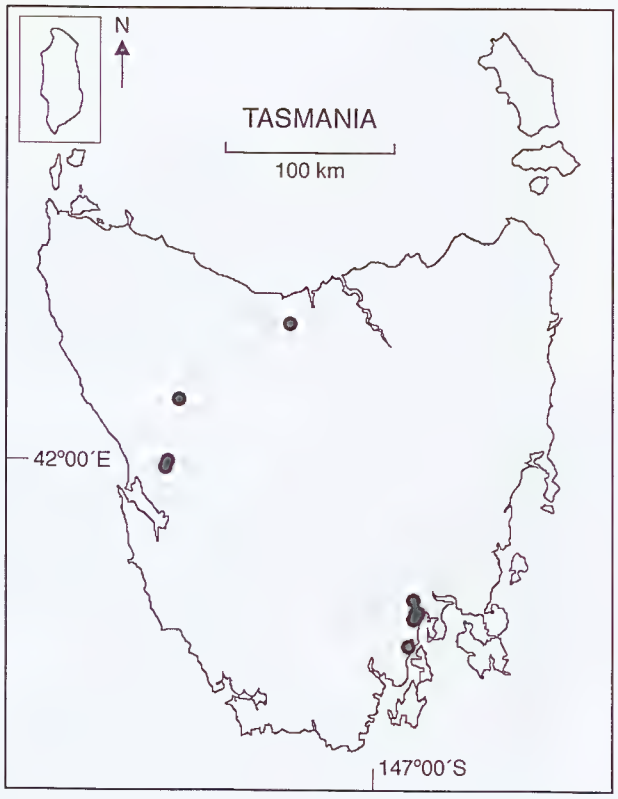

FIG. 1 — Geographical distribution of Cotoneaster glaucophyllus *var.* serotinus *as known from herbarium specimens.*

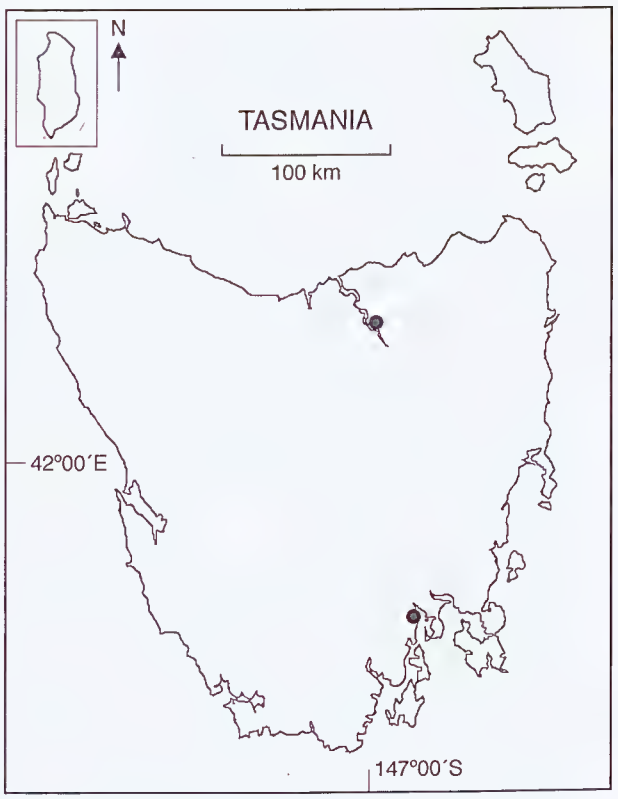

FIG. 2 — Geographical distribution of Cotoneaster pannosus *as known from herbarium specimens.*

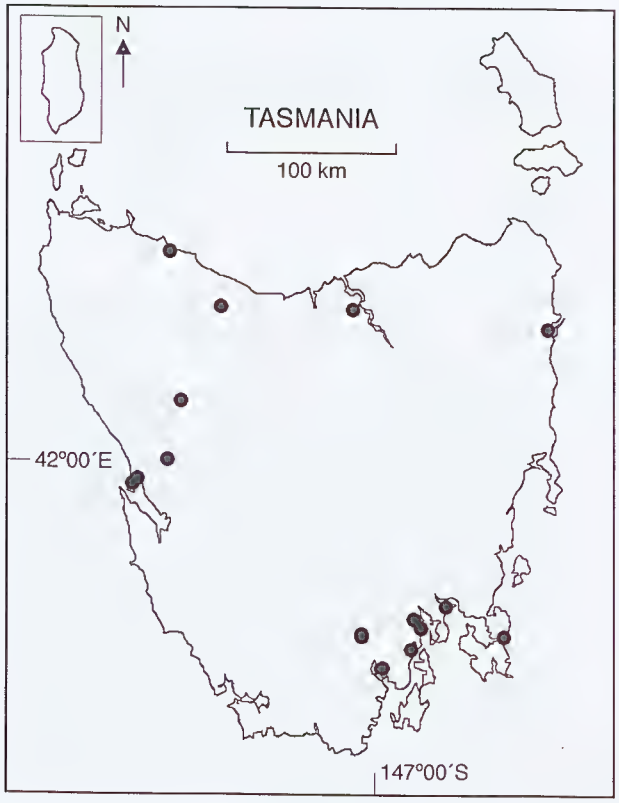

FIG. 3 — Geographical distribution of Cotoneaster franchetii *as known from herbarium specimens.*

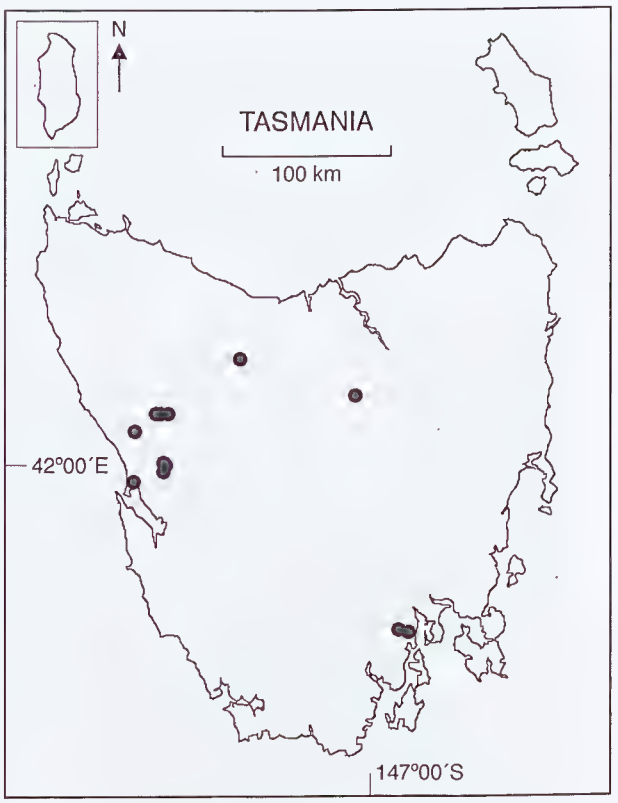

FIG. 4 — Geographical distribution of Cotoneaster simonsii *as known from herbarium specimens.*

17 Jan. 1999, D.E. Symon 15943 (HO, AD). Upper Natone, South Riana Road, 1 Nov. 2004, M. Baker 857 (HO).

1d. *Cotoneaster simonsii* Hort. ex Baker, *Refug. Bot.* 1: t.55 (1869). (Rosaceae)

Common name: Khasia berry, Himalayan cotoneaster.

Illustration: pl. 1C.

Description: A deciduous or sometimes semi-evergreen shrub 2–3(–4) m tall. Young stems densely pubescent, becoming glabrous with age. Leaves sometimes distichous, 15–30 mm long, 7–15 mm long, elliptic, rhombic or ovate; apex acute to apiculate, dark green and sparsely pubescent above, pale green and more densely pubescent below but with the lamina still visible between the hairs; petiole 2–3.5 mm long; apex acute to apiculate. Flowers 1–4(5), in corymbs; sepals 1.5–2 mm long, triangular; petals erect, 2–3 mm long, obovate, white with pink markings. Fruit up to 10 mm long, obovoid, orange-red, with 3–4 pyrenes.

For a comprehensive description see Sykes & Given (1988).

Discussion: *Cotoneaster simonsii* was first recognised as being present in Tasmania in January 1999, by D.E. Symon. Rozefelds *et al.* (1999) recorded *C. simonsii* from two Tasmania specimens. Subsequently other Tasmanian collections that were misidentified as *C. glaucophyllus*, *C. franchetii* and *C. divaricatus* Rehder & E.H. Wilson were re-identified as *C. simonsii* (*C. divaricatus* is not recorded as naturalised in Tasmania). Several recent collections of *C. simonsii* have also been made.

Distribution and habitat: *C. simonsii* is native to the Himalayas and east India (Phipps *et al.* 1990). It has been introduced widely as an ornamental. It is naturalised in New Zealand where it has been noted forming a dominant understorey in conifer plantations (Sykes & Given 1988). It is also naturalised in Britain, Ireland, France and Norway (Browicz 1968). In Australia, it is naturalised in South Australia (Symon 1986), Victoria (Ross & Walsh 2003) and New South Wales (Botanic Gardens Trust 2005). In Tasmania, it is naturalised in the West Coast, East Coast, Midlands and North-West regions (fig. 4). It is most common in the West Coast region where it is found in a wide range of habitats including roadside cuttings in wet sclerophyll forest with mixed rainforest species, coastal woodland with a weedy understorey, a buttongrass plain under weedy *Pinus radiata* and on a river bank in residential Queenstown. In some areas within the West Coast, it is locally common and populations of over 200 plants have been recorded.

First record: 1985, A. Moscal.

Specimens examined: **TASMANIA**: *West Coast region*: Murchison Highway, 4.5 km W of Rosebery, 23 Jan. 1985, A. Moscal 9504 (HO). Outskirts of Queenstown on road from Strahan just after turn off to Strahan and by Queenstown Civil Construction Depot, 20 Jan. 1999, D.E. Symon 15955 (HO, AD). Alongside Jones Street, Strahan 16 Jan. 1998, J.R. Hosking 1557 (HO, AD, CANB, MEL, NE, NSW). South Queenstown, 50 m E of bridge leading to cemetery, 14 Sep. 2004, M. Baker 494 (HO). Queenstown, park section of Esplanade. Queen River, 100 m S of Penghana Road bridge, 16 Sep. 2004, M. Baker 660 (HO). Zeehan, cemetery reserve S of Zeehan, off Henty Road, 15 Sep. 2004, M. Baker 552 (HO). E of Rosebery, Murchison Highway, 15 Sep. 2004, M. Baker 560 (HO). Murchison Highway, 1.5 km W of Rosebery golf course, 15 Sep. 2004, M. Baker 599 (HO). *Midlands region*: Jackeys Marsh Road, Apr. 1996, J. Robin (HO). *North-West region*: Moina Road near Bismuth Creek, 19 Jul. 1992, A.M. Buchanan 12436 (HO). *East Coast region*: Huon Road, c. 2 km NE of Lesley Vale Road junction 05 May 2000, A.M. Gray 1048 (HO).

2. *Genista linifolia* L., *Sp. Pl.* edn. 2, 2: 997 (1763). (Fabaceae)

Common name: flaxleaf broom.

Illustration: Jeanes (1996a, p. 824, fig. 168h); pl. 2A.

Description: Small erect shrub to 2(–3) m tall. Stems pubescent when young, glabrous with age. Leaves sessile, 3-foliate, decurrent at the base and forming three longitudinal ridges where ajoining the stem; leaflets linear to narrow oblanceolate, 10–25(–27) mm long, 2–4(–6) mm wide, with under surface densely covered with appressed grey hairs and upper surface green, sparsely hairy, becoming glabrous with age; apex mucronate; stipules absent. Flowers in short terminal racemes with 5–14 flowers per raceme; calyx pale green, up to 9 mm long, clothed in fine white hairs; corolla bright yellow; standard sparsely hairy on the outer surface, up to 13.5 mm long and 10.5 mm wide; wings up to 13 mm long and 4.5 mm wide; keel hairy on outer surface, to 13 mm long; stamens fused around the carpel. Pod narrow-oblong, densely pubescent, 17–23 mm long, to 6 mm wide, containing 3–7 seeds.

For a comprehensive description see Jeanes (1996a) and Webb (1988, as *Teline linifolia* (L.) Webb & Berthel.).

Discussion: *Genista* L. is a genus of 87 species from Europe, the Canary Islands and the Mediterranean region to western Asia (Mabberly 1997). The genus is represented in Tasmania by three naturalised alien species: *G. monspessulana* (L.) L.A.S. Johnson, *G. stenopetala* Webb & Berthel. and *G. linifolia*. Rozefelds *et al.* (1999) recorded *Genista linifolia* from Tasmania. Based upon a single herbarium specimen. *G. linifolia* was first recorded in Tasmania in 1996 and later in 1998. Both specimens were collected from the Queens Domain, Hobart. Notes accompanying these collections lacked population details or information indicating the species' naturalised status. A visit to the site in 2004 revealed two distinct populations of *G. linifolia*. A third population was recorded at Long Beach, Sandy Bay, in October 2005.

Genista linifolia can be distinguished from other naturalised Tasmanian species, *G. monspessulana* and *G. stenopetala*, by using the following key. The general morphology of the flowering branches of the three naturalised *Genista* species is illustrated in pl. 2.

Key to the species of *Genista* in Tasmania

1. Leaves sessile; leaflets linear to narrow oblanceolate; stipules absent ..... ***G. linifolia***
1: Leaves petiolate; leaflets elliptic to obovate; stipules present..... 2
2. Inflorescences short racemes occurring at the end of short lateral branches, axis < 10 mm long, 3–7-flowered ***G. monspessulana***
2: Infloresences short to long terminal racemes, axis 10-130 mm long, 5–30(–40)-flowered..... ***G. stenopetala***

Distribution and habitat: *Genista linifolia* is native to the western Mediterranean region where it is usually a calcifuge (Gibbs 1968, as *Teline linifolia* (L.) Webb & Berthel.). It is naturalised in New Zealand on dry coastal cliffs and roadsides, probably as an escape from cultivation (Webb 1988). In Australia, it is naturalised in New South Wales,

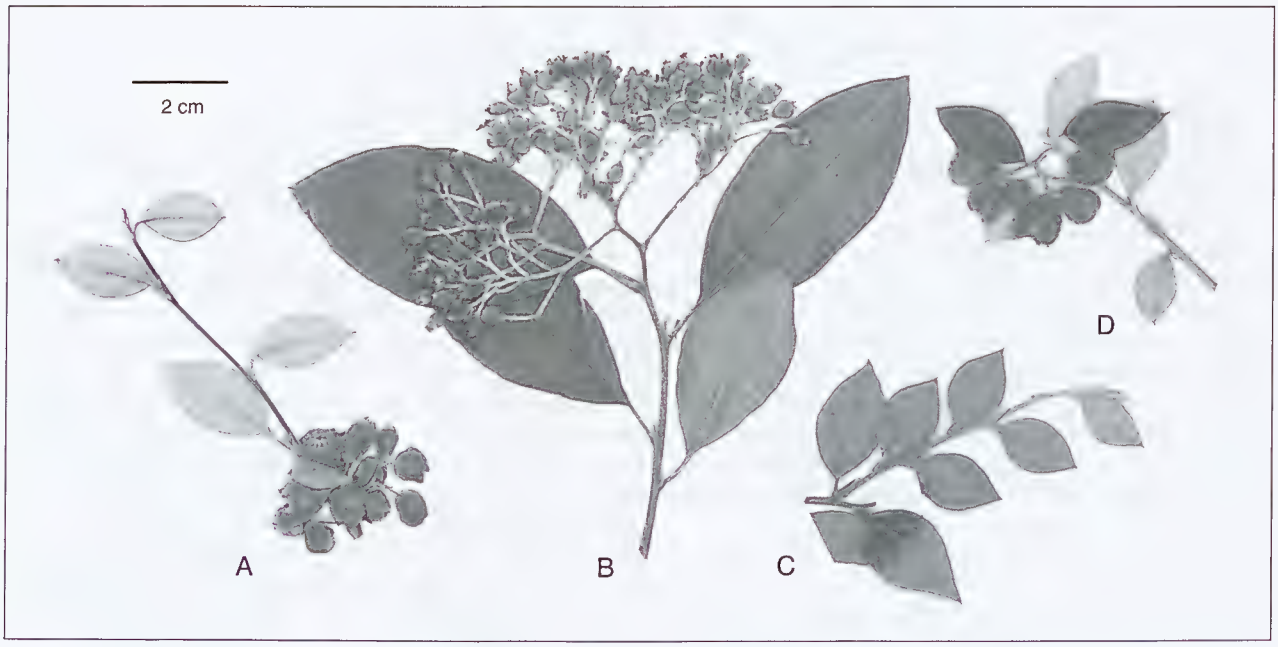

PLATE 1
Fruiting branches of naturalised Cotoneaster *species. A.* Cotoneaster pannosus. *B.* Cotoneaster glaucophyllus *var.* serotinus. *C.* Cotoneaster simonsii. *D.* Cotoneaster franchetii.

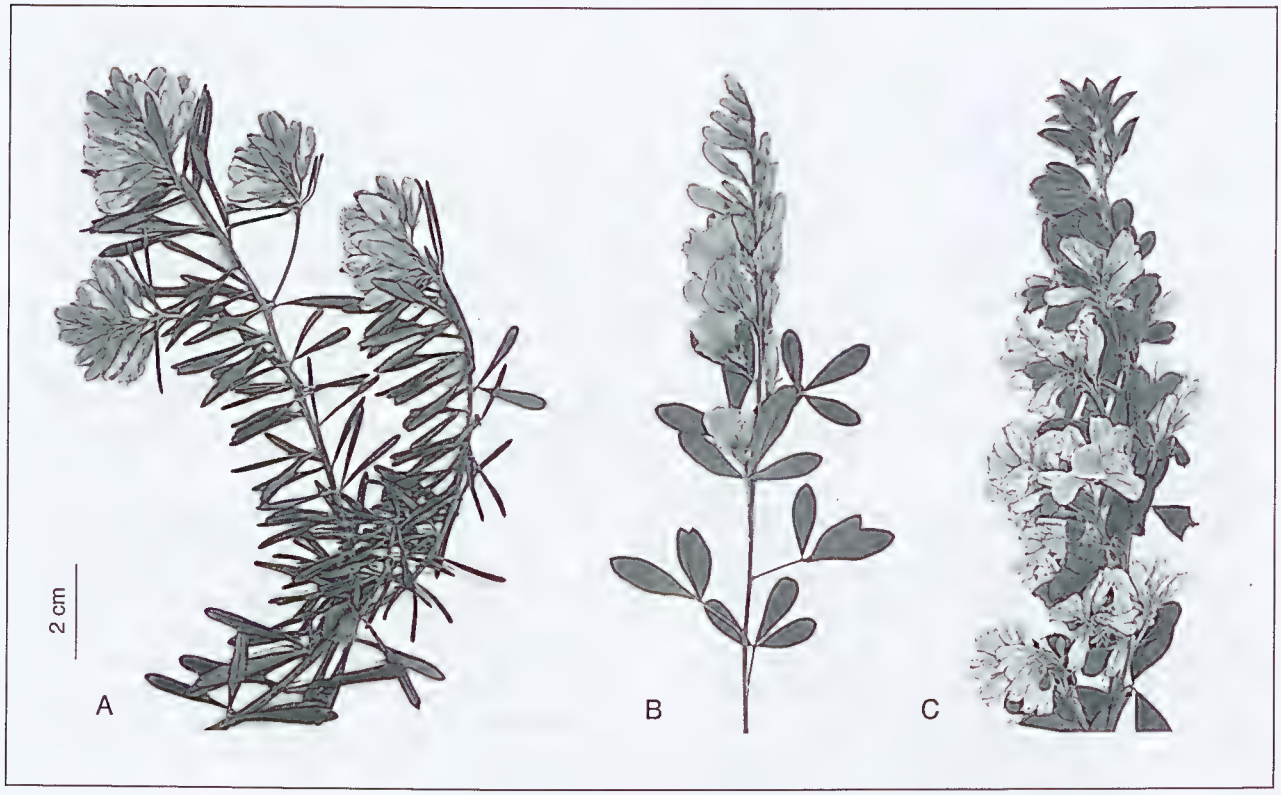

PLATE 2
Flowering branches of naturalised Genista *species. A.* Genista linifolia. *B.* Genista stenopetala. *C.* Genista monspessulana.

Victoria, South Australia and Western Australia, where it is a weed of roadsides, drains, fence lines and encroaches onto pastureland as an escape from cultivation (Parsons & Cuthbertson 2001). In Tasmania, it is known from three populations in the East Coast region (fig. 5). At the Queens Domain one population consisted of a small number of young plants c. 30 cm tall and some larger shrubs. The other, and larger, of the two populations comprised numerous large shrubs to c. 1.5 m tall and several hundred smaller plants to c. 10 cm tall (presumably kept low by regular mowing). This population covered an area of approximately 500 m^2. None of the plants in either of the two populations appeared to be planted. Both populations have since undergone active weed control. At the Sandy Bay site *G. linifolia* was a dominant component of a steep, weed-infested embankment, growing in association with numerous weedy shrubs, including *Lycium ferocissimum* Miers, *Paraserianthes lophantha* (Willd.) I.Nielsen and *Chrysanthemoides monilifera* (L.) Norlindh. Nearly ten years have passed since it was first recorded, but observations indicate that it could become more common as an invader of bushland, roadsides and disturbed sites throughout Tasmania.

First record: 1996, P. Toonen.

Specimens examined: **TASMANIA**: East Coast region: Queens Domain, Hobart, old oil depot site, 14 Jun. 1996, P. Toonen (HO). Queens Domain, at T.S. Derwent [Hobart], 9 Jun. 1998, A.M. Buchanan 15273 (HO). Queens Domain, bike track between Tasman Bridge and Cenotaph, 19 Oct. 2004, M.L. Baker 752 (HO). Long Beach, Sandy Bay, 24 Oct. 2005, M.L. Baker 1646 (HO). **VICTORIA**: Wonthaggi area. Kilcunda Foreshore Reserve, opposite Kilcunda shops on old railway line, 28 Aug. 1989, R.W. Robinson 3 (HO, MEL, CANB). Hurstbridge, corner of Haleys Gully and Broad Gully Roads, 11 Oct. 1981, R.A. Kilgour 99 (HO, MEL). Blackburn, E suburb of Melbourne. Blackburn Lake Sanctuary 22 Sep. 1981, T.B. Muir 6633 (HO, MEL).

3. *Kunzea ericoides* (A.Rich.) Joy Thomps., *Telopea* 2: 379 (1983). (Myrtaceae)

For synonymy see Thompson (1983).

Common name: burgan.

Illustration: Jeanes (1996b, p. 1021, fig. 210j-l); pl. 3A-B.

Description: Upright to somewhat spreading shrub to 3 m tall. Young stems reddish, pubescent, becoming glabrous and stringy barked with age. Leaves subsessile, alternate, oblanceolate, erect to spreading, ± flat, 4–19.5 mm long, 2–3.2 mm wide, with hairs confined to margin and midvein, becoming glabrous with age, dotted with glands (glands more noticeable on dried material), pleasantly aromatic, especially when crushed. Flowers on pedicels 3–6.5 mm long, crowded on leafy side branches and in upper leaf axils; sepals green, triangular, c. 1 mm long; petals white, orbicular, to 2.5 mm diam.; stamens white, 1–4 mm long, some shorter than the petals; ovary with 3–5 locules; style 1.5–2.5 mm long. Fruit to 3 mm long, 3.5–4 mm diam., opening by terminal valves.

For a comprehensive description see Jeanes (1996b). Australian mainland specimens have been described as reaching up to 5 m tall, with leaves to 25 mm long and 4.5 mm wide (Jeanes 1996b).

Discussion: *Kunzea* Rchb. is a genus of 35 species endemic to Australia and one species (*K. ericoides* (A.Rich.) Joy Thomps.) that occurs in Australia and New Zealand (Mabberly 1997). The genus is represented in Tasmania by a single native species, *K. ambigua* (Sm.) Druce, and one naturalised species, *K. ericoides* (Buchanan 2004). *K. ericoides* was first recorded in Tasmania in late 2000 where it had escaped from cultivation into nearby bush and roadside at Kingston (East Coast region). The age of naturalised plants at this site was estimated as ranging between 1 and 10 years old (A.M. Gray pers. comm.). It has since been collected from other sites where plants have escaped from cultivation and colonised adjacent ground.

Kunzea ericoides is a polymorphic species that varies in many vegetative characters (Jeanes 1996b; Wilson 2002). It can be distinguished from the native Tasmanian species *K. ambigua* by using the following key. General morphology of both *Kunzea* species is illustrated in pl. 3.

Key to the species of *Kunzea* in Tasmania.

1. Leaves 2–3.2 mm wide, ± flat; flowers on pedicels 3–6.5 mm long; some stamens shorter than petals; style to 2.5 mm long ..... ***K. ericoides***
1: Leaves 1–1.5 mm wide; concave above and keeled below; flowers ± sessile; all stamens longer than petals; style to 5 mm long ..... ***K. ambigua***

Distribution and habitat: *K. ericoides* is native to Victoria, New South Wales, Queensland and New Zealand (Thompson 1983). Evidence on the Australian mainland indicates that, although native, it has spread beyond its native range (Singer & Burgman 1991) and has also colonised pasture (Kirschbaum & Williams 1991). In Victoria, it is often associated with riparian habitats (Jeanes 1996b). In Tasmania, there are several records from the East Coast region and single records from each of the North-East, Midlands and North-West regions (fig. 6). This species is commonly found in gardens and amenity plantings in the Kingborough Municipality (A.M. Gray pers. comm.). Observations indicate it will become more common as an invader of bushland, roadsides and disturbed sites throughout Tasmania. The species spreads small distances by seed falling close to parent plants (Singer & Burgman 1991). Distant spread of seed might be aided by water movement and by equipment contaminated with seed.

First record: 2000, A.M. Gray.

Specimens examined: **TASMANIA**: *East Coast region*: Summerleas (Kingston) Country Fire Station, 8 Dec. 2000, A.M. Gray 1082 (HO). Summerleas Fire Station, lower Summerleas Road, 1 km from A6 (Huon Highway), 12 Jan. 2001 A. M. Gray 1086 (HO). Lower Summerleas Road fire station grounds, 12 May 2004, A.M. Gray 1379 (HO). Lower Snug, Channel Highway, W side, 100–200 m S of Folk Museum, 22 Dec. 2004, M.L. Baker 1224 (HO). *Midlands region*: Symmons Plains, 15 Oct. 2001, J. Worth (HO). *North-East region*: 3 km N of start of Gardens Road. Before Binalong, N of Grants Lagoon, late 2004–early 2005, P. Stafford (HO). *North-West region*: Stony Rise Government Offices, Devonport, 21 Sep. 2005, M.L. Baker 1614 (HO). **VICTORIA**: Batesford Sanctuary, near Dog Rocks on Moorabool River. Private land, 2 Jan. 1977, G. W. Carr 7305 (HO, MEL). Melbourne (outer suburb); corner of Ringwood, Warrandyte and Croydon Roads, S Warrandyte (private property), 1 Dec. 1982, R.A. Kilgour 338 (HO, MEL). **NEW ZEALAND**: 3 km beyond Rissington, Hawkes Bay, 15 Jun. 1984, A.M. Buchanan 3679 (HO, MEL, NSW).

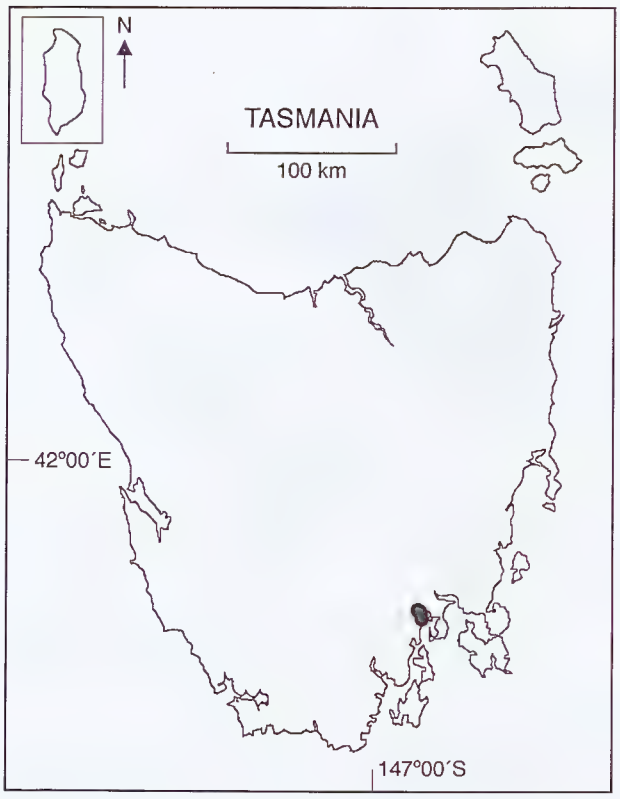

FIG. 5 — Geographical distribution of Genista linifolia *as known from herbarium specimens.*

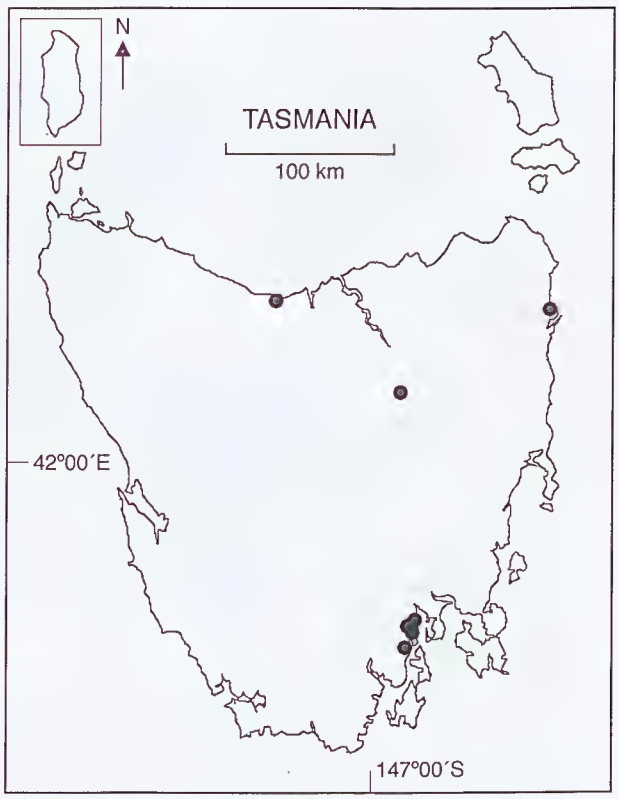

FIG. 6 — Geographical distribution of Kunzea ericoides *as known from herbarium specimens.*

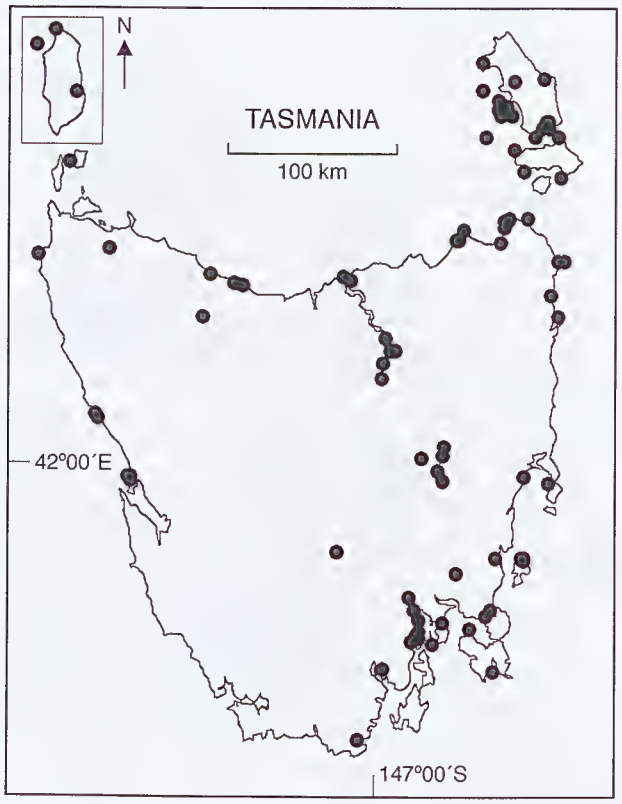

FIG. 7 — Geographical distribution of Plantago coronopus *subsp.* coronopus *as known from herbarium specimens.*

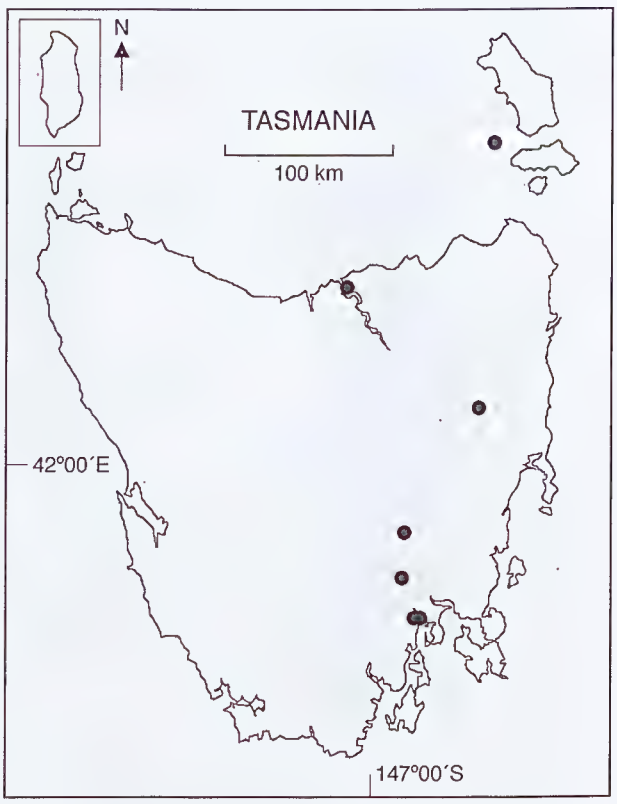

FIG. 8 — Geographical distribution of Plantago coronopus *subsp.* commutata *as known from herbarium specimens.*

PLATE 3
Kunzea. *A-B.* Kunzea ericoides. *A. Flowering branch (left) and fruiting branch (right). B. Close up of infloresence and leaves. C-D.* Kunzea ambigua. *C. Close up of infloresence and leaves. D. Flowering branch.*

4. *Plantago coronopus* L., *Sp. Pl.* 1: 115 (1753). (Plantaginaceae)

Common name: buck's horn plantain.
Description: Pubescent taprooted perennial or annual. Leaves in a rosette, oblong to narrow oblong in outline, 1–20 cm long, 0.5–2 cm wide, pinnatifid or deeply toothed, occasionally entire in depauperate specimens. Spike 1–11 cm long, densely flowered; scape to 29 cm long, 0.5–2.3 mm diam.; bracts broadly ovate, 2–3.8 mm long, acuminate. Sepals 4, ovate to elliptic, unequal, 2.1–2.8 mm long, keeled, with keel of anterior sepals more or less equal in width or broader than the membranous margin; corolla tube 1–1.5 mm long, pubescent, with 4 lobes to 1.3 mm long, spreading to reflexed. Capsule ovoid, 2–2.5 mm long; seeds to about 1 mm long, brown.

For a comprehensive description see Jeanes (1999).
Discussion: *Plantago* L. is a cosmopolitan genus of approximately 270 species (Mabberly 1997), represented in Tasmania by 13 indigenous (six of which are endemic) and five alien taxa. An account of the genus in Tasmania is provided by Brown (1991) who lists two subspecies of *P. coronopus* for Tasmania: subsp. *coronopus* and subsp. *commutata* (Guss.) Pilg. Until recently, the Tasmanian vascular plant census (Buchanan 2004) and specimens in the collection at the Tasmanian Herbarium have only recognised *P. coronopus* to specific rank.

Plantago coronopus subsp. *coronopus* can be distinguished from *P. coronopus* subsp. *commutata* by using the following key from Brown (1991). The habit and detail of the inflorescence of the two subspecies is illustrated in pl. 4.

Key to the subspecies of *Plantago coronopus* in Tasmania

1. Scapes slender (0.5–1.8 mm diam.), usually longer than the leaves; bracts mostly longer than the sepals; keel width of anterior sepals ± equal to width of membranous margins ..... ***P. coronopus* subsp. *coronopus***
1: Scapes stout (1.3–2.3 mm diam.), usually shorter than or equal to the leaves; bracts mostly shorter than or equal to the sepals; keel width of anterior sepals broader than membranous margins ... ***P. coronopus* subsp. *commutata***

4a. *Plantago coronopus* L. subsp. *coronopus* (Plantaginaceae)
Common name: buck's horn plantain.
Illustration: Jeanes (1999, p. 468, fig. 91d); pl. 4C-D.
Description: Diagnostic features as in key. Plants with leaves up to 30 cm long have been recorded in Victoria (Jeanes 1999).
Distribution and habitat: *Plantago coronopus* subsp. *coronopus* is native to Europe and western Asia. In Australia, it is naturalised in all states and territories. In Victoria, it is usually found in disturbed sites and is often abundant in near-coastal locations (Jeanes 1999). It is common and widespread throughout Tasmania where it is a weed of turf, pasture, roadsides and disturbed areas. It is particularly common in coastal situations, but has been collected inland at altitudes up to 550 m. It is a very well collected taxon with c. 90 Tasmanian specimens held at HO (fig. 7).
First record: 1881, A. Simson.
Selected specimens examined (of c. 100 collections): **TASMANIA:**

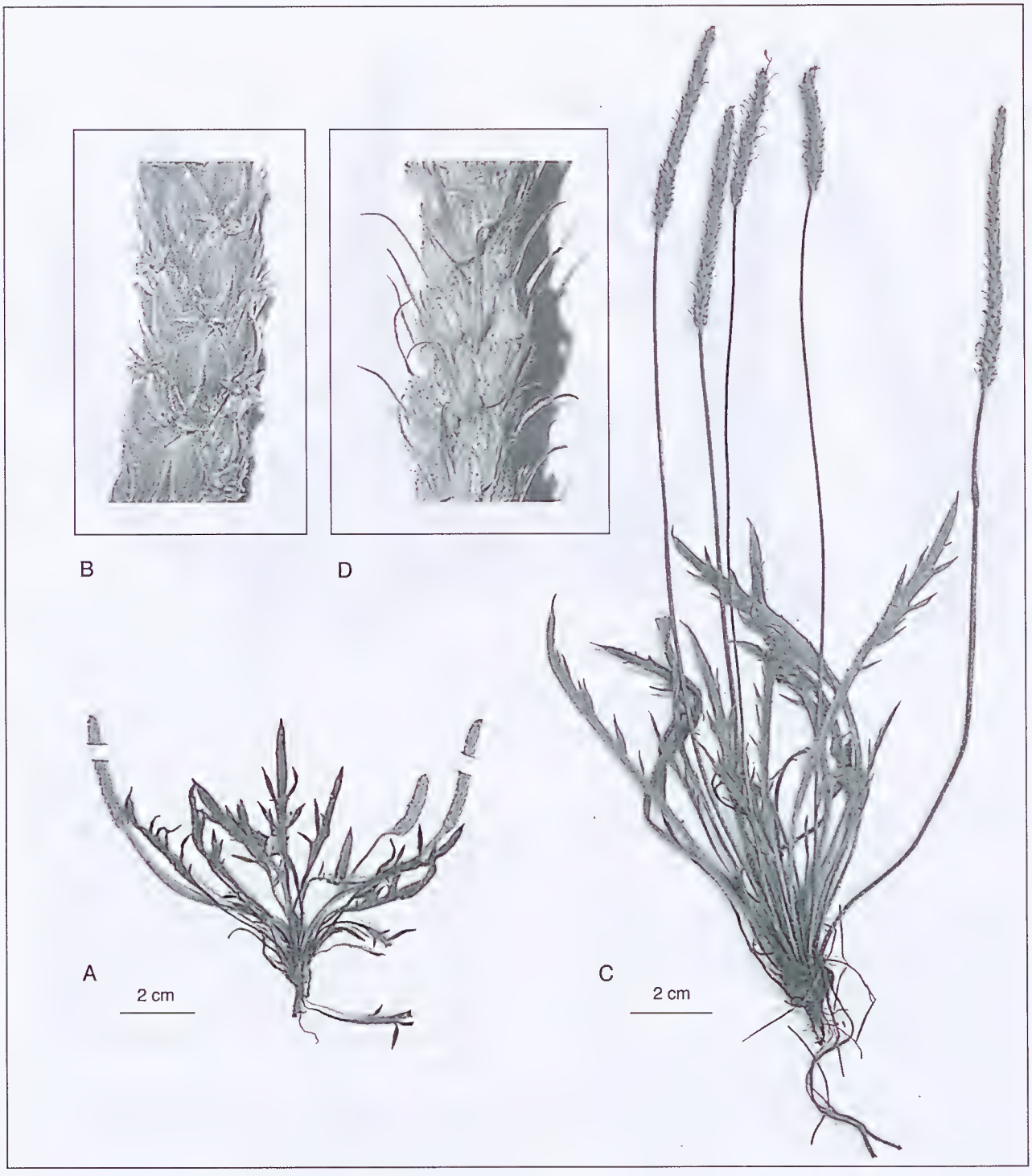

PLATE 4

Plantago coronopus. *A-B. subsp.* commutata. *A. Habit. B. Close up of inflorescence. C-D. subsp.* coronopus. *C. Habit. D. Close up of inflorescence.*

East Coast region: Swansea, Oct. 1881, A. Simson 2177 (HO). Creek Road, New Town, 7 Oct. 1980, D.I. Morris 8086 (HO). *West Coast region*: Ocean Beach, 11 Jan. 1984, A. Moscal 5478 (HO). Granville Harbour, 24 Apr. 1988, P. Collier 3117 (HO). **NEW SOUTH WALES**: Gunning Showground, 13 Jan. 1992, B.J. Lepschi 701 (HO, CANB). **SOUTH AUSTRALIA**: Beachport, 26 Jan. 1969, J. Carrick 2177 (HO, AD).

4b. *Plantago coronopus* L. subsp. *commutata* (Guss.) Pilg., *Repert. Spec. Nov. Regni Veg.* 28: 287 (1930). (Plantaginaceae)

Common name: buck's horn plantain.

Illustration: Jeanes (1999, p. 468, fig. 91e); pl. 4A-B.

Description: Diagnostic features as in key.

Discussion: See under subsp. *coronopus* (above).

Distribution and habitat: *Plantago coronopus* subsp. *commutata* is native to Europe, western Asia and northern Africa. In Australia, it is naturalised in the Australian Capital Territory, New South Wales, Queensland, South Australia, Victoria, Western Australia and Tasmania. In Victoria, it is scattered mostly in the drier inland areas in the western part of the state, often associated with disturbed sites on sandy soils (Jeanes 1999). In Tasmania, subsp. *commutata* has been collected from inland and coastal situations (fig. 8). It is not as common as subsp. *coronopus*, as illustrated by there being only eight Tasmanian specimens in HO.

First record: 1844, R.C. Gunn.

Specimens examined: **TASMANIA**: *East Coast region*: Spring Hill, S of Oatlands on Midland Highway, 24 Jan. 1931, L. Rodway (HO). Hobart, Jan. 1892, L. Rodway 629 (HO). Bellerive, 2 Feb. 1930, F.H. Long 130 (HO). South Esk between Avoca and Ormley, 10 Nov. 1942, H. D. Gordon (HO). Brighton, 'Winton', Dec. 1876, W.W. Spicer (HO). *North-East region*: George Town, 21 Nov. 1844, R.C. Gunn (HO). *Furneaux region*: Hogan Island, 14 Nov. 1984, N.P. Brothers, 206 (HO). Badger Island. Chappell group, 12 km SW of Flinders Island, 30 Nov. 1986, S. Harris (HO). **VICTORIA**: Dookie Agricultural College, 13 Nov. 1937, B. Shoobridge (HO). **NEW SOUTH WALES**: Between Nerriga and Charleyong, on Braidwood to Nowra road, 2 Dec. 1975, R. Pullen 10.214 (HO, CANB).

TAXA OF UNCERTAIN STATUS

5. *Hypericum humifusum* L., *Sp. Pl.* 1: 785 (1753). (Clusiaceae)

Common name: trailing St John's-wort.

Illustration: Walsh (1996, p. 320, fig. 63l-m); pl. 5.

Description: Glabrous, perennial herb. Stems procumbent or decumbent, to 6 cm long, with two longitudinal ridges. Leaves sessile, elliptic to obovate, up to 5 mm long, up to 3 mm wide, with black intramarginal glands and pale glands scattered throughout; apex obtuse. Inflorescence terminal, 1–few-flowered; sepals 5, to 3.8 mm long, slightly unequal in width, with two broad and three narrow, with black glands; petals up to twice as long as sepals, yellow, with black glands towards the apex; stamens ± half as long as petals; styles 3. Capsule equal to or slightly longer than sepals.

This description is based on one specimen held at HO and the comprehensive descriptions in Sykes (1988) and Walsh (1996). The Tasmanian specimen is a depauperate plant. Descriptions of New Zealand material in Sykes (1988) indicate that the species can have stems to 30 cm long and leaves to 14 mm long and 6 mm wide. Walsh (1996) describes Victorian material with leaf dimensions similar to that in New Zealand.

Discussion: *Hypericum* L. is a genus of c. 370 species, mainly found in temperate to tropical regions (Mabberly 1997). The genus is represented in Tasmania by two native species and five naturalised alien species (including *H. humifusum*) (Buchanan 2004). A key including all Tasmanian species can be found in Sykes (1988). Recent work on *Hypericum* by R. Francis (unpublished) recognised the presence of *H. humifusum* in Tasmania, based on one Tasmanian specimen previously identified as the native *H. japonicum* Thunb. This species was previously unrecorded for Tasmania.

Hypericum humifusum somewhat resembles the two Tasmanian native species, *H. japonicum* and *H. gramineum* Forst.f. However, it can be easily distinguished from both species by the presence of black glands on the leaves and flowers (pl. 5).

Distribution and habitat: *H. humifusum* is native to western and central Europe and northern Africa where it inhabits open sites and is usually a calcifuge (Robson 1968). It is naturalised in New Zealand where it is distributed widely and found in a wide range of habitats including 'poorer pastures and tussock grasslands on hill slopes to c. 500 m, on dry stony roadsides and banks, as well as on wet heavy soils in open, but particularly shady areas' (Sykes 1988). In Australia it is naturalised in Victoria where it is said to favour disturbed, open habitats near streams (Walsh 1996).

In Tasmania, it is recorded from one location at Don River, Devonport (fig. 9). The sparse notes accompanying the sole specimen describe the habitat as clay soil. No population details are recorded. This species has not been recorded since its first collection in 1940. Although recently cited in Buchanan (2004) as naturalised, further surveys and collections of this plant would be required to determine its status in Tasmania.

First record: 1940, A.M. Olsen.

Specimens examined: **TASMANIA**: *North-West region*: Don River, Devonport, 9 Jan. 1940, A.M. Olsen (HO).

6. *Solanum americanum* Mill., *Gard. Dict.* edn 8 no.5 (1768). (Solanaceae)

For synonymy see Purdie *et al.* (1982).

Common name: glossy nightshade.

Illustration: Symon (1981, p.38, fig. 1).

Description: Annual or short-lived perennial herb, often bushy, up to 1.3 m high, often with mauve or purplish colouration, glabrous or sparsely clothed with simple hairs. Leaves with petiole 1–4 cm long; lamina ovate or ovate-lanceolate to 12 cm long and 7 cm wide, more commonly to 6 cm long and 3 cm wide, entire or with shallow lobes. Inflorescence umbellate with 4–12 flowers; peduncle to 25 mm long, lengthening to 45 mm long and deflexing as fruit matures; pedicels 5–8 mm long. Calyx 1–2 mm long, strongly reflexed at fruiting stage; corolla 8–9 mm diam., white or tinged purple with a yellow-green centre. Berry 6–9 mm diam., globular, purple-black, glossy, with stone cells.

This description is based on one specimen held at HO and the comprehensive descriptions in Symon (1981) and Purdie *et al.* (1982).

Discussion: *Solanum* L. is a cosmopolitan genus of c. 1700 species (Mabberly 1997). The genus is represented in Tasmania

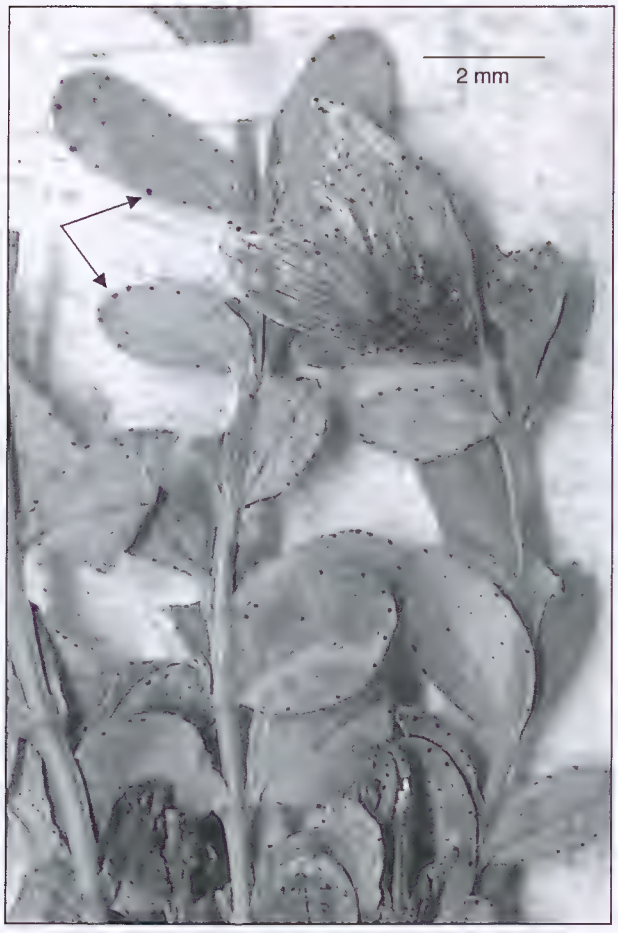

PLATE 5
Flowering stem of Hypericum humifusum. *Arrows point to characteristic black glands.*

by three indigenous and eight naturalised alien species (including *S. americanum*) (Buchanan 2004). Comprehensive treatments of all taxa occurring in Tasmania are found in Purdie *et al.* (1982). In November 2003, specimens of the genus held at the Tasmanian Herbarium were curated as part of the Australian Virtual Herbarium (AVH) project. During their curation, the identity of one specimen, recorded previously as *S. nigrum* L., was redetermined as *S. americanum* by D.I. Morris. This species was previously unrecorded in Tasmania.

Solanum americanum could be confused with *S. nigrum*, the most common weedy species of the genus found in Tasmania. The two species can be distinguished by the following characteristics: the latter has calyx lobes appressed to the fruit and dull black mature fruit, usually without stone cells. The former has calyx lobes strongly reflexed at the fruiting stage and glossy black fruits with stone cells.

Distribution and habitat: *S. americanum* is widespread in tropical and warm temperate regions of the world. In Australia it is thought to be either indigenous or introduced prior to European settlement in Queensland and New South Wales, from where it subsequently spread into Victoria, Northern Territory and Western Australia (Purdie *et al.* 1982). It occurs in a wide range of habitats and colonises areas following disturbance (Symon 1981).

Within Tasmania it is known only from one location at Clarence Point, West Tamar, where it was collected from

PLATE 6
Setaria pumila *subsp.* pumila. *A. Flowering culm. B. Mature spikelet.*

an area of disturbed ground on the margin of *Eucalyptus viminalis* Labill. forest (fig. 10). Although included in the Tasmanian census by Buchanan (2004) as 'sparingly naturalised', further surveys are required to confirm the extent of its occurrence. A brief reconnaissance of the site in 2004 failed to find this species. The species may be more widespread in Tasmania and has possibly been overlooked in the past due to its resemblance to *S. nigrum*.

First record: 1993, A.M. Buchanan.
Specimen examined: **TASMANIA**: *Midlands Region*: Clarence Point, West Tamar, 28 Sep. 1993, A.M. Buchanan 13453 (HO).

NEW INCURSIONS

7. *Setaria pumila* (Poir.) Roem. & Schult., *Syst. Veg.* 2:891 (1817) subsp. *pumila* (Poaceae)

For synonymy see Webster (1987).
Common name: pale pigeon-grass.
Illustration: Tothill & Hacker (1996, p. 374); pl. 6–7.
Description: Tufted annual, up to 80 cm tall. Leaves with blade 4–10 mm wide, glabrous or with some hairs towards the base; ligule to 1.5 mm long, ciliate. Panicle dense and spike-like, 1–15 cm long. Spikelets 3–3.4 mm long, subtended by several antrorsely scabrous bristles which are 3–10 mm long. Lower glume 30–40% spikelet length, with 3–5 nerves; upper glume 45–65% spikelet length, with 5–9 nerves. Lower lemma usually sterile, as long as spikelet, with 5 nerves; palea from slightly shorter to as long as lemma. Upper lemma as long as spikelet, strongly transversely rugose; palea similar to lemma.

For comprehensive descriptions see Webster (1987) and Sharp & Simon (2002).
Discussion: *Setaria* P. Beauv. is a genus of c. 110 species, mostly found in tropical and warm temperate regions of the world. Many of the species are adventive and significant weeds (Watson & Dallwitz, 1994). Hitherto, the genus was represented in Tasmania by four naturalised, alien species; *S. parviflora* (Poir.) Kerguélen (syn, *S. gracilis* Kunth var. *pauciseta* (Desv.) B.K. Simon), *S. italica* (L.) P. Beauv. *S. verticillata* (L.) P. Beauv. and *S. viridis* (L.) P. Beauv. (Curtis & Morris 1994, Buchanan 2004, Sharp & Simon 2002). *S. pumila* subsp. *pumila* was first recorded in Tasmania in March 2004, when a sample, collected from ground around an amenity tree-planting in West Hobart, was submitted for identification.

This species resembles other naturalised *Setaria* species that occur in Tasmania. *Setaria* species are recognised by having panicles which are cylindrical and spike-like, and by having spikelets which are subtended by one to several scabrous bristles. *S. pumila* subsp. *pumila* can be distinguished from the other Tasmanian species by using the following key, which has been adapted from Curtis & Morris (1994). The general morphology of a flowering culm and detail of a mature spikelet of *S. pumila* subsp. *pumila* are illustrated in pl. 6.

Key to the species of *Setaria* in Tasmania

1. Involucral bristles retrorsely scabrous ... ***S. verticillata***
1: Involucral bristles antrorsely scabrous 2
2. Lemma of upper floret strongly transversely ridged, with apex tapered to a minute apical point 3
2: Lemma of upper floret smooth or granular but not boldly ridged, with apex blunt 4
3. Plants annual, without rhizomes; leaves mostly wider than 5 mm; bristles generally considerably longer than spikelets ..... ***S. pumila* subsp. *pumila***
3: Plants perennial, with horizontal, branched, knotty rhizomes; leaves mostly narrower than 4 mm; bristles generally about as long as spikelets ..... ***S. parviflora***
4. Plant up to 150 cm high; panicle 2.5–30 cm long; glumes persistent; palea of lower floret reduced to a minute scale or absent ..... ***S. italica***
4: Plant up to 75(–90) cm high; panicle 1–10 cm long; glumes falling with the florets; palea of lower floret up to ½ as long as the lemma ..... ***S. viridis***

Distribution and habitat: *S. pumila* subsp. *pumila* is native to the warmer parts of Europe and Asia and possibly northern Australia (Walsh 1994). According to Sharp & Simon (2002) this grass is introduced to Australia and occurs in all Australian mainland states except the Northern Territory. It is a common weed throughout south-east Queensland, the subtropics and warmer temperate regions of the world (Tothill & Hacker 1996). In Victoria, it is uncommon and is an occasional weed of well-watered sites, such as irrigated crops, gardens and riverbanks (Walsh 1994).

Within Tasmania this species is known only from one location in West Hobart, where it was collected from a single tree amenity planting (fig. 11). A survey of the site revealed only a few plants that were growing in association with *Taraxacum officinale* Weber ex F.H. Wigg., *Echinochloa crus-galli* (L.) P. Beauv., *Trifolium repens* L. and *Plantago lanceolata* L. All were growing at the base of the tree covering an area of approximately 1m² (pl. 7). It is likely that the tree in this planting was obtained from a mainland advanced

PLATE 7
Habitat of Setaria pumila *subsp.* pumila *at the only known site in Tasmania.*

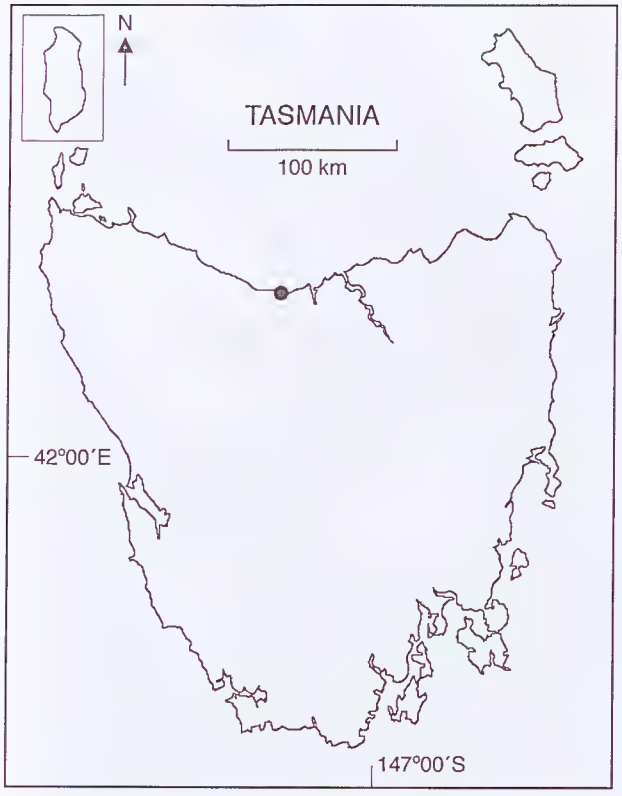

FIG. 9 — Geographical distribution of Hypericum humifusum *as known from herbarium specimens.*

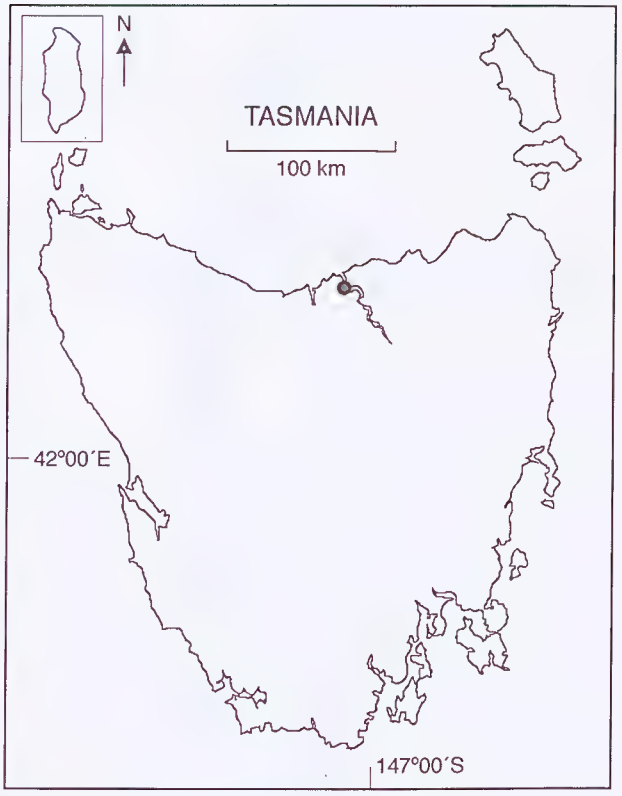

FIG. 10 — Geographical distribution of Solanum americanum *as known from herbarium specimens.*

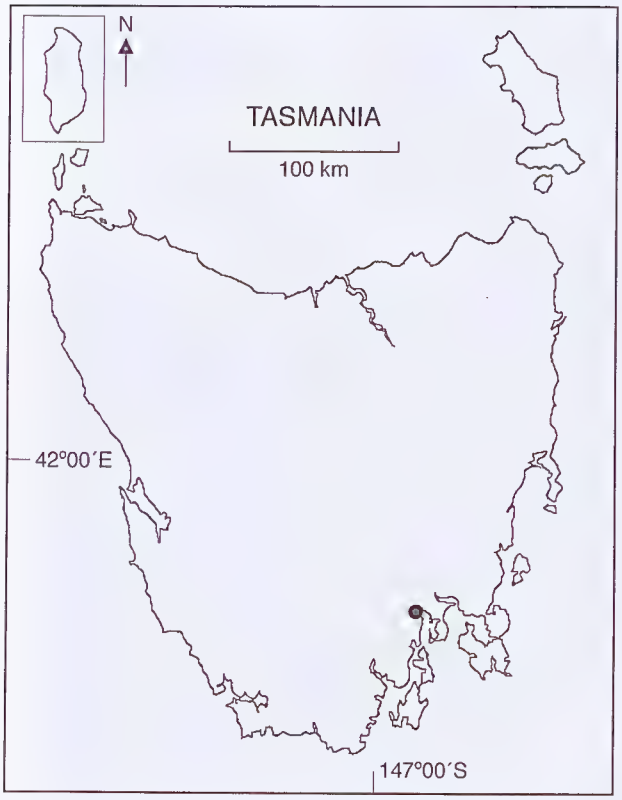

FIG. 11 — Geographical distribution of Setaria pumila *subsp.* pumila *as known from herbarium specimens.*

tree nursery, and the grass possibly was introduced to the site as a contaminant of the tree's root-ball.

A reconnaissance of the surrounding area, including residential gardens and other amenity plantings, failed to find further plants. The plants were removed and destroyed.

First record: 2004, M.L. Baker.

Specimens examined: **TASMANIA:** *East Coast region:* West Hobart, Hill Street, 10 Mar. 2004, M.L. Baker 396 (HO, MEL, CANB, NSW). **QUEENSLAND:** Samford Research Station, 25 May 1966, R.B. Warner (HO). **NEW SOUTH WALES:** Port Jackson district, no date, no collector, ex Herb. Rodway (HO). Richmond River, no date, no collector, ex Herb. Rodway (HO).

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(accepted 9 October 2005)

A PRELIMINARY CENSUS OF THE MACROFUNGI OF MT WELLINGTON, TASMANIA – THE ASCOMYCOTA

by Genevieve M. Gates and David A. Ratkowsky

(with one appendix)

Gates, G. M. & Ratkowsky, D. A. 2005 (16:xii): A preliminary census of the macrofungi of Mt Wellington, Tasmania – the Ascomycota. *Papers and Proceedings of the Royal Society of Tasmania* 139: 49–52. ISSN 0080-4703. School of Plant Science, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia (GMG*); School of Agricultural Science, University of Tasmania, Private Bag 54, Hobart, Tasmania 7001, Australia (DAR). *Author for correspondence.

This work continues the process of documenting the macrofungi of Mt Wellington. Two earlier publications were concerned with the gilled and non-gilled Basidiomycota, respectively, excluding the sequestrate species. The present work deals with the non-sequestrate Ascomycota, of which 42 species were found on Mt Wellington.

Key Words: Macrofungi, Mt Wellington (Tasmania), Ascomycota, cup fungi, disc fungi.

INTRODUCTION

Two earlier papers in the preliminary documentation of the macrofungi of Mt Wellington, Tasmania, were confined to the 'agarics' (gilled fungi) and the non-gilled species, respectively (Ratkowsky & Gates 2002, Gates & Ratkowsky 2004), all within the Division Basidiomycota. Those papers, which identified 206 macrofungal species between them, completed the preliminary census of the macrofungi whose spores are borne on basidia, with the exception of the truffle-like 'earthballs', which will be the subject of the fourth and final part of this project. Naming of the species in the earlier papers was facilitated by the publication of two recent catalogues of the Australian Basidiomycota (May & Wood 1997, May *et al.* 2003) and the maintenance of an updated interactive version of those catalogues on the Royal Botanic Gardens Melbourne website (www.rbg.vic.gov.au). However, no catalogue exists as yet for the Australian Ascomycota, a large division of fungi in which spores are contained within asci, rather than upon basidia. Although such a catalogue is planned as part of the Fungi of Australia project, it is unlikely to be realised for at least five years (T.W. May pers. comm.). Therefore, so as not to delay unreasonably a listing of the Ascomycota of Mt Wellington, we have undertaken to produce this third paper in the series, without reference to an updated catalogue.

MATERIALS AND METHODS

Details of the survey zones appear in Ratkowsky & Gates (2002); that paper included a map of the survey area. The fieldwork for the project commenced in January 1994 and is part of a continuing programme of fungal surveys throughout Tasmania. Between April 1998 and August 2005, over 300 visits to Mt Wellington were made. Forays were divided into six areas or groups of tracks, viz. (i) the extensive network of tracks centred near Ferntree on the east-facing slopes of Mt Wellington, (ii) Myrtle Gully and Old Farm trails, (iii) Myrtle Forest Creek above Collinsvale, (iv) the track towards Cathedral Rock along the North West Bay River, (v) the Waterworks Reserve, Hobart, and (vi) the Truganini Track from Cartwright Creek, Taroona, to Mount Nelson. Visits were made in each of the twelve months of the year.

For the purposes of this survey, all Ascomycota having a conspicuous fruiting body were considered, excluding endophytes. Material collected during forays was described macroscopically shortly after collection, and examined microscopically to obtain details such as the size of the asci, details of the paraphyses, and spore shape, size and ornamentation. Species identification was aided by comparing the detailed macro and micro descriptions with those of published species in the scientific literature, from websites and other information on the Internet, and, in a few cases, by consultation with overseas mycologists specialising in the Ascomycota. Voucher material for each species has been deposited in the Tasmanian Herbarium (HO) and, wherever sufficient material was available, in the National Herbarium of Victoria (MEL).

RESULTS

The list of the macrofungal Ascomycota in appendix 1, in keeping with the standard adopted in the previous papers in this series, is confined to those taxa that have been validly named. The 42 named species listed in appendix 1 may only be a fraction of the true number present on Mt Wellington. Other genera such as *Leucoscypha* and *Ascobolus* are represented on Mt Wellington as well as other species of *Mollisia*, *Ciboria* and *Lachnum*. However, the authors have not been able to determine the specimens to species level. When a more comprehensive study has been made on the Ascomycota, further named species will become available.

The species are listed alphabetically within each of five Orders, as given by Kirk *et al.* (2001). In a few cases, there is some doubt about whether the taxa occurring in Tasmania are conspecific with those named from elsewhere (usually the Northern Hemisphere), so "aff." is used to indicate that the species has an affinity with the species of that name from the place of the original description. Only the above-ground (i.e., non-sequestrate) species are considered here, with the truffle-like Ascomycota to be part of the fourth part of this series of papers. For the species listed in appendix 1, wherever there are photographs and/or illustrations available in published sources, references to these are given.

DISCUSSION

Maintenance of high levels of biological diversity is thought to be important for ecosystem health and resilience. Fungi make up a large proportion of the diversity in any ecosystem and are biologically important, especially with respect to nutrient recycling and mycorrhizal associations. The lists of taxa in this series of papers provide the baseline data needed for ongoing assessment of changes in biological diversity and health in Mt Wellington's ecosystems. Although the Ascomycota are the most diverse group of fungi (Kirk *et al.* 2001), the lists provided here are, of necessity, preliminary and incomplete. The authors have tried to determine the specimens they have collected as best as they can. The lack of taxonomic resources for Australia's Ascomycota, there being few monographic studies and no catalogue and bibliography, has meant this has often been impossible.

Three examples where taxonomic study is necessary to resolve problems are mentioned here. One of these involves *Hypoxylon rubiginosum*, whose fruit bodies form large patches of red-purple crusts on dead wood. This species is often reported from Australia (e.g., McCann 2003, Fuhrer 2005). However, a monograph on *Hypoxylon* (Ju & Rogers 1996) suggests that *H. rubiginosum* does not extend to the Antipodes, and the species in Australia may be more closely allied to, or conspecific with, *Hypoxylon placentiforme* (J. D. Rogers pers. comm.). The second example involves the species often reported in Australia as *Xylaria polymorpha* (McCann 2003, Fuhrer 2005). Although believed by some to be a cosmopolitan species, a revision of the genus *Xylaria* in New Zealand (Rogers & Samuels 1986) did not report that species from that country. Tasmanian material sent to one of the authors of that work, Prof. J. D. Rogers, was identified by him as *X. castorea* Berk., a species with very much smaller spores than those of *X. polymorpha*. The third example involves the species often cited in Australia as *Daldinia concentrica*, but which is listed here as *D. grandis* on the advice of Prof. J. D. Rogers.

While it is not possible to predict how many species of Ascomycota might be present on Mt Wellington, it is clearly a greater number than reported in this preliminary study. Only concerted taxonomic efforts will provide a more realistic estimate of the true number.

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APPENDIX 1

Species descriptions of Ascomycota of Mt Wellington

[Helotiales]

Ascocoryne sarcoides (Jacq.) J.W. Groves & D.E. Wilson – The mature sexual stage consists of pink-purple discs having a gelatinous texture, found singly or gregariously on rotting wood in wet forests. The conidial stage has pink, club-shaped fruit bodies. Illustrations – McCann (2003, p. 111); Fuhrer (2005, p. 301); Grey & Grey (2005, p. 111).

Bisporella citrina (Batsch ex Fr.) Korf & S.E. Carp. – Consists of small, yellow discs, seldom exceeding 3 mm diameter, flattened with age, the stipe very small, on rotting wood. Cosmopolitan. Illustrations – Fuhrer & Robinson (1992, p. 85); Grgurinovic & Mallett (1996, fig. 17); McCann (2003, p. 112); Fuhrer (2005, p. 304).

Bisporella sulfurina (Quél.) S.E. Carp. – Similar to *Bisporella citrina* (q.v.), the tiny, sulphur-yellow discs on wood are rarely greater than 1.5 mm diameter, the habit is gregarious rather than clustered, and the spores are narrower than in the related species. Illustrations – Breitenbach & Kränzlin (1984, species 178).

Chlorociboria aeruginascens (Nyl.) Kanouse ex Ramamurthi, Korf & Batra – Easily identified by the small, blue-green discs and the blue-green staining imparted to the wood on which this fungus grows. Shepherd & Totterdell (1988, p. 146, as *Chlorosplenium aeruginascens*); Fuhrer & Robinson (1992, p. 84); Bougher & Syme (1998, p. 95); McCann (2003, p. 112); Fuhrer (2005, p. 306); Young (2005, plate 34, as *Chlorosplenium aeruginascens*).

Ciboria peckiana (Cooke) Korf – Occurring on wood, disc concave or depressed at centre, brown or grey-brown, smooth, receptacle cup-shaped with a short stalk, brown or greyish brown, distinctly furrowed towards the stalk. Illustration – Spooner (1987, fig. 50).

Discinella terrestris (Berk. & Broome) Dennis – Occurring on soil, often at the base of trees or tree ferns, the pale orange or yellow-orange, flattened discs are irregularly undulate. Illustrations – McCann (2003, p. 113); Fuhrer (2005, p. 315).

Geoglossum cookeanum Nannf. – An "earth tongue" on soil, blackish throughout, dry when fresh, ascospores regularly 7-septate. Illustration – A similar-appearing species, possibly the same species, is illustrated by McCann (2003, p. 110, as *Geoglossum* sp.).

Hymenoscyphus pezizoideus (Cooke & W. Phillips) Gamundí – Creamy grey to greenish grey discs, often forming colonies on bark, twigs and small branches in forests. Illustrations – McCann (2003, p. 113); Fuhrer (2005, p. 313), both as *Cudoniella pezizoidea*.

Lachnum lachnoderma (Berk.) G.G. Hahn & Ayers – Forms small, individual, shortly stalked, cream-coloured or yellowish discs with white hairs densely covering the underside of the fruit body. On small twigs and branches.

Lanzia lanaripes (Dennis) Spooner – Occurring on wood, the tack-like apothecia have a greenish black to blackish brown disc, appearing smooth, with a long stalk. Illustrations – McCann (2003, p. 113, as *Rutstroemia* sp.); Fuhrer (2005, p. 325).

Leotia lubrica (Scop.) Pers. – Occurring on soil, the fruit bodies have an irregularly spherical, lobed to knobbly, viscid to slimy, yellow or yellow-green pileus, mounted on a tall, viscid, yellow or yellow-green stalk. Illustrations – Arora (1986, plate 215); McCann (2003, p. 113); Fuhrer (2005, p. 326); Grey & Grey (2005, p. 117).

Mollisia aff. *cinerea* (Batsch ex Mérat) P. Karst. – A blue-grey, sessile disc, 1–3 mm diameter, forming large groups on rotting wood. Illustration – Breitenbach & Kränzlin (1984, species 274).

Torrendiella eucalypti (Berk.) Spooner – Cup to 2 mm diameter, yellowish white when fresh, drying pale yellow, on a slender cylindrical or downward tapering stalk, the margin rimmed with stiff, well-spaced, dark brown, septate hairs, the remainder of the receptacle without hairs. Often found on fallen phyllodes of *Acacia melanoxylon*. Illustration – Beaton & Weste (1977, fig. 1, as *Zoellneria eucalypti*).

[Hypocreales]

Cordyceps gunnii (Berk.) Berk. – *Cordyceps* are insect pathogens, the exposed, fertile part of the fruiting body arising from parasitised insect larvae. The above-ground portion is a stout, elongated club with a yellowish stem and a dark olive-green to blackish head. The below-ground portion, emerging from a buried caterpillar host, may be as long as, or longer than, the above-ground portion. Illustrations – Grgurinovic & Mallett (1996, fig. 16); Mallett & Grgurinovic (1996, fig. 29); Fuhrer (2005, p. 311); Grey & Grey (2005, p. 104).

Cordyceps robertsii (Hook.) Berk. – The above-ground portion is brown-coloured, may be simple or branched, and tapers gradually to a long, slender point. Illustrations – Fuhrer & Robinson (1992, p. 90); Fuhrer (2005, p. 312).

Cordyceps taylori (Berk.) Sacc. – The above-ground portion of the fertile head of this large species may divide into numerous stout, staghorn-like branches. Illustration – Willis (1950, plate 16).

Hypocrea aff. *sulphurea* (Schwein.) Sacc. – Forming broad patches on the undersides of dead wood in forests, the bright, sulphur-yellow resupinate surface is densely covered throughout with fine, dark ostioles. Illustration – Fuhrer (2005, p. 320).

Nectria cinnabarina (Tode) Fr. – This parasitic species on wood has perithecia clustered in small, red or red-orange, erumpent groups, and may be accompanied by a cushion-like, pinkish anamorph. Illustration – Courtecuisse & Duhem (1995, p. 129).

[Pezizales]

Aleuria aurantia (Fr.) Fuckel – The stalkless, flattened, and often irregularly undulate, orange-coloured cup fungus grows on soil in forests and disturbed areas. Illustrations – Arora (1986, plate 208); Shepherd & Totterdell (1988, p. 148); McCann (2003, p. 114); Fuhrer (2005, p. 298).

Aleuria rhenana Fuckel – Distinguished from *A. aurantia* (q.v.) by its more pronounced, deeply concave, orange cup and the presence of a well-defined, pallid orange or whitish stalk, found on soil in forests. Illustrations – Arora (1986, plate 209); Bougher & Syme (1998, p. 93); McCann (2003, p. 115); Robinson (2003, p. 59); Fuhrer (2005, p. 299).

Aleurina calospora (M.A. Rifai) Korf & W.Y. Zhuang – The fruit bodies, found on litter in wet forests, are dark rusty brown to purple-brown cups up to 1 cm diameter, with the outer surface covered by numerous dark brown, conical warts. The darker colours of the fruit body, the more broadly ellipsoidal spores, and the massive spore ornamentation help distinguish this species from *Aleurina ferruginea* (q.v.). Illustration – Rifai (1968, figs 62-64, microscopic characters only).

Aleurina ferruginea (W. Phillips ex Cooke) W.Y. Zhuang & Korf – The brown or rusty-brown, concave discs found on soil are covered with fine warts over its margin and lower surface. Illustrations – McCann (2003, p. 115); Fuhrer (2005, p. 299).

Anthracobia muelleri (Berk.) M.A. Rifai – The small brownish orange discs, only a few millimetres in diameter, concave or flattened, with short marginal hairs, often form densely crowded masses on burnt soil and plant material

after bushfires. Illustration – Fuhrer (2005, p. 300). The illustration in McCann (2003, p. 115, as *Anthracobia* sp.) may be of the same species.

Cheilymenia coprinaria (Cooke) Boud. – Cups orange to red, stalkless, with a fringe of stiff hairs, the hairs septate, brownish, rooted in the outer tissue of the excipulum. On dung. Illustration – Bell (1983, fig. 32); Bell (2005, fig. 36 A–F). The illustration in McCann (2003, p. 115, as *Cheilymenia* sp.) may be of the same species.

Gyromitra esculenta (Pers.) Fr. – The contorted, lobed, wrinkled or brain-like stalked caps on soil have a different internal structure from the morels (*Morchella*) and are never conical or deeply pitted. Usually brown or purple-brown. Illustrations – Arora (1986, plate 206); McCann (2003, p. 114); Fuhrer (2005, p. 318).

Morchella elata Fr.: Fr. – The Black Morel is a very variable, cosmopolitan species or species group, occurring in narrow-headed or broad-headed forms, usually quite dark, with vertically-aligned ridges and pits. Found on soil. Illustrations – Arora (1986, plates 199 and 202); McCann (2003, p. 114); Robinson (2003, p. 63); Fuhrer (2005, p. 329); Grey & Grey (2005, p. 114).

Nothojafnea cryptotricha M.A. Rifai – Occurring on soil or amid moss. Apothecia deeply concave, dark reddish brown to dark brown cups, outer surface smooth or indistinctly hairy, stalk furrowed. Illustrations – Rifai (1968, figs 78-84, microscopic characters only); McCann (2003, p. 117).

Peziza tenacella W. Phillips ex Cooke – Cups deep lilac-violet and smooth on the inside, paler and minutely scurfy on the outside. Cups may reach 8 cm diameter, on burnt ground. Illustration – Fuhrer (2005, p. 333).

Peziza vesiculosa Bull.: Fr. – Fruit bodies large, gregarious, light brown, deeply concave, margin usually inrolled, often irregularly incised, brittle. Spores large, smooth. Found on dung, manured ground and decaying woody materials. Illustrations – McCann (2003, p. 118); Fuhrer (2005, p. 334); Young (2005, p. 63, watercolour); Bell (2005, fig. 34 A–E).

Peziza thozetii Berk. – Apothecia brown, often bluish beneath and with blue trama, medium sized, with inrolled, entire margin. The spores are microscopically distinctive in having a conical apiculus at each end. On soil. Illustrations – Rifai (1968, fig. 267, spores only); Fuhrer (2005, p. 333).

Pletania campylospora (Berk.) Nannf. – The fruit body is a large, rubbery cup up to 8 cm diameter, the inner surface brown, smooth, the outer surface brown to black, rough, mounted on a short, rough, central stem. On rotting wood or on soil. Spores suballantoid, 23–32 x 9–14 µm, smooth. Illustrations – Rifai (1968, figs 4–5, microscopic characters only); Grgurinovic & Mallett (1996, fig. 18); McCann (2003, p. 119); Fuhrer (2005, p. 335); Grey & Grey (2005, p. 109).

Plectania platensis (Speg.) M.A. Rifai – The fruit bodies are medium to large cups, the upper surface deeply concave, brownish black to almost black, smooth, with the lower surface marked by vertical ridges, brownish black, finely tomentose or velvety. On dead eucalypt wood. Spores 19–23 x 8.5–12 µm, ornamented with horizontal striations. Illustration – Rifai (1968, figs 10–14).

Scutellinia margaritacea (Berk. ex Cooke) O. Kuntze – This species of *Scutellinia* found on soil is characterised by orange, flat cups with a margin of multiple tiers of fine black or blackish hairs. Spores 27–33 x 14–19 µm. We have also found specimens with smaller spores (17–23 x 11–13 µm) on Mt Wellington, and these are probably referrable to *Scutellinia scutellata* (L.: Fr.) Lamb. Schumacher (1990) considered that the Tasmanian species described as *S. pseudomargaritacea* Le Gal was conspecific with *S. margaritacea*. Illustrations – Bougher & Syme (1998, p. 109) and McCann (2003, p. 116) illustrate species of this complex genus.

[Rhytismatales]

Therrya eucalypti Z.Q. Yuan – Fruit bodies immersed to erumpent, irregularly shaped, ca. 1.2 x 1.5 mm, black, the hymenium orange. Spores long and narrow, 78 x 2.6 µm, hyaline, fusiform, 2-5 septate. Paraphyses filiform. On dead eucalypt branches. Illustration – Yuan & Mohammed (1997, figs 1-5).

[Xylariales]

Daldinia grandis Child – The broadly rounded, pinkish brown, firm to hard fruit bodies, found on decaying wood, blacken with age and are covered with minute ostioles. Concentric growth zones are seen when the fruit bodies are cut in half. Illustrations – Bougher & Syme (1998, p. 97); McCann (2003, p. 119); Robinson (2003, p. 67); Fuhrer (2005, p. 315), all as *Daldinia concentrica*.

Hypoxylon bovei Speg. – The black fruit bodies on wood may be single or coalesced into broad, hard patches, each fruit body shaped like a truncated cone with an upraised pimple-like apex and ostiole. Spores 10.5–13 x 5–6.5 µm. Illustration – Fuhrer (2005, p. 321).

Hypoxylon crocopeplum Berk. & M.A. Curtis – Forms reddish brown or orangey brown flat cushions on wood with the spherical or obovoid perithecia embedded in the cushion, and the ostioles lower than or at the same level as the stromatal surface. Spores 9.5–15 x 4–7 µm.

Hypoxylon diatrypeoides Rehm – The fruit bodies look like flattened black spots or scabs covering dead or decaying logs in wet forests. Spores 17–23 x 8.5–10 µm. Illustration – The photo in McCann (2003, p. 120, as *Hypoxylon* sp. 'Black Spot') may be of the same species.

Hypoxylon howeanum Peck – The small fruit bodies on wood form hemispherical mounds in patches up to 2 cm long, the surface fulvous, rust or dark brick, the perithecia spherical to obovoid, embedded in the stromatal surface. Spores 7–9.5 x 3–4.5 µm.

Hypoxylon aff. *placentiforme* Berk. & M.A. Curtis – The fruit bodies have the form of thin crusts, red-purple, lilac or violaceous, on the undersides of dead logs, up to a metre or more long. The ostioles cover the surface as fine, whitish dots. Illustrations – McCann (2003, p. 120); Fuhrer (2005, p. 323), both as *H. rubiginosum*.

Xylaria castorea Berk. – Fruit bodies unbranched, cylindrical or spathulate, to 8 cm high, black, the surface with fine ostioles. Interior flesh white, with the black perithecia near the margin. Spores 9–11 x 5–6 µm. Widespread in Tasmania on dead wood, this species is often reported as *X. polymorpha*, which has much larger spores. Illustrations – McCann (2003, p. 121); Fuhrer (2005, p. 341), both as *X. polymorpha*.

Xylaria aff. *hypoxylon* (L.) Grev. – On wood. Fruit bodies cylindrical, clavate or flattened, often branched at the apices, upper portion powdery white in the conidial stage, becoming black at maturity, with the stalk black, hairy. Illustrations – McCann (2003, p. 121); Robinson (2003, p. 65); Fuhrer (2005, p. 340).

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THREE SEEMINGLY UNRELATED PROPOSITIONS CONCERNING AUSTRALIA'S IDENTITY AND ECONOMIC PERFORMANCE

by Saul Eslake[a]

Eslake, S.R. 2005 (16:xii): Three seemingly unrelated propositions concerning Australia's identity and economic performance. *Papers and Proceedings of the Royal Society of Tasmania* 139: 53–60. ISSN 0080–4703. A.N.Z. Bank, Level 10, 100 Queen Street, Melbourne, Victoria 3000, Australia.

In three selected respects, Australia's institutions and culture both reflect and influence our national identity and in so doing, it is argued, detract from Australia's economic performance. Australia's tax system favours the accumulation of wealth through borrowing and speculative investment rather than through working and saving. Australia's popular culture values excellence in sport but in little else (reflecting which, governments and business devote resources to the pursuit of sporting excellence but in little else). Finally, Australian governments, like some governments overseas, have responded to the threats perceived to be posed by terrorism and corporate malfeasance in ways that have significantly added to costs and detracted from productivity whilst doing little to reduce the threat from either.

Key Words: Tax reform, negative gearing, double standard, pursuit of excellence, talent, security, corporate governance, productivity.

I'm deeply honoured to be invited to talk to the Royal Society of Tasmania. I'm on the record as saying that if I had thought, as a callow youth, that I could have made a living as an historian then I would have sought to become one. And despite having chosen instead to become an economist, I've remained enough of an amateur historian to be aware of this Society's role in fostering knowledge, particularly but not exclusively in the natural sciences, since its foundation in 1843, the first such Society to be founded outside the United Kingdom. Since I'm neither a scientist nor an academic, and make no claim to have 'pushed out the frontiers of knowledge' even in my own field of economics, I feel particularly humbled and not a little daunted at being invited to speak to such an auspicious gathering.

Rather than making new discoveries in the field of economics, I regard my role as helping, however imperfectly, the corporation for which I work and its customers, and to the extent possible the broader communities within which it operates, better to understand the environment in which they carry out their activities, and thus to make better informed business and investment decisions. In that sense, I'm motivated, as I always have been, by the belief so eloquently expressed by the Nobel Laureate in Economics the late James Tobin, that economics 'offer[s] the hope … that improved understanding could better the lot of mankind'.[b]

I don't want to overstate the importance of economics in this, or any other regard. I've always thought that Maynard Keynes' assertion that 'the world is ruled by little else' than 'the ideas of economists, both when they are right and when they are wrong'[c] was an exaggeration, both when he made it in 1936 and since – although the fact that he made it nearly 60 years ago does put into a more appropriate perspective the commonly-made claim that economists have had 'too much' influence over public policy in recent years.

But I do share the opinion of Paul Krugman – who may well win a Nobel Prize in Economics one day if he spends more time on economics and less time writing polemics against the Bush administration in the columns of the *New York Times*, well written though they are, and much as I find myself agreeing with many of them – that 'economists may make lots of bad predictions, but they do have a method – a systematic way of thinking about the world that is more true than not, that gives them genuine if imperfect expertise. That is also why lay commentators and other social scientists tend to hate them'[d].

Tonight I want to step outside my normal 'territory' to speak about three issues which, though seemingly unrelated, in my opinion have, in their different ways, some bearing on the kind of nation and society we are – that is, on our identity – as well as on the performance of our economy.

Because I am stepping outside the 'territory' normally inhabited by economists, I want to emphasise, more strongly than the usual disclaimer implies, that I am speaking solely for myself, and that my views do not purport to represent, and should not be taken as representing, those of my employer.

And I also want to stress that although I am going to disagree, expressly in some instances and by implication in others, with a number of prominent and powerful individuals, that I am not criticising them for having opinions from which I differ.

It is, I think, regrettable that – as I have discovered myself – it is becoming more difficult to express opinions which in some way diverge from those of people in positions of power or authority, or to suggest that some alternative perspective or policy might be worth considering, without that being taken as tantamount to treason, and cause for retribution of some kind against oneself or one's employer. However, that is an issue which, for now at least, I will leave to others to pursue.

Thirdly, I should perhaps emphasise that it is not my intention to say what Australia's identity *should* be. For any one individual to do so is, I think, quite arrogant; and for a government to attempt to do it is kind of scary. Equally arrogant, I believe, are attempts to suggest that Australia has some kind of monopoly on particular values. We are of course entitled to believe that Australia is 'the best country in the world in which to live' – as I do – but we should be able to do that without claiming that values such as 'equality', 'tolerance', 'respect for the rule of law' or even 'mateship' are somehow uniquely Australian.

Rather, what I want to do this evening is to spell out how, in my opinion, Australia's present approach to three separate issues influences the kind of society we are, and how – again, only in my opinion – changing that approach could make Australia an even better country in which to live.

Proposition 1: A country's tax system says something important about the kind of society it wants to be, and has an influence on the kind of society it is. Australia's tax system sends the wrong messages and has perverse economic consequences.

The first of these three issues, which I start with only because it is closer to my 'territory' as an economist than the other two, and because quite by coincidence it has assumed particular prominence in recent days, is Australia's tax system.

I want to emphasise at the outset that it is not my purpose to argue that Australians pay too much tax (for what it's worth I don't believe we do); or conversely that we should pay more (I don't believe that either). Rather, I want to talk about the *way* in which we collect the taxes which we do.

If you were to invite a team of consultants to design a tax system with the explicit objective of discouraging the accumulation of wealth by working and saving, and instead to encourage the accumulation of wealth through borrowing and acquiring assets expected to appreciate in value at a faster rate than the CPI, they would find it difficult to come up with a better 'solution' than to hand you a copy of the existing Australian income tax legislation. Being consultants, they would probably charge you for several thousand person-hours of work; but in practice, they would simply download a copy of the *Income Tax Act* from the ATO's website and turn it into a book of Powerpoint slides.

Australia's tax system is riddled with exemptions, concessions and deductions which are explicitly designed to favour particular types of income or expenditure over others, and saddled with provisions designed to prevent people from using those exemptions, concessions and deductions in ways that were not intended by those who put them there so as to reduce the amount of tax which they are obliged to pay. That is why Australia's income tax legislation now runs to over 9,000 pages – more, as the Shadow Treasurer Wayne Swan points out, than the Sydney, Melbourne, Brisbane, Perth and Adelaide White Pages combined.[e]

Common and integral to each of the three major rounds of tax reform in Australia over the past two decades has been the principle of broadening the tax base and lowering tax rates:

First, the reforms implemented by the Hawke-Keating Government in the 1980s, which brought previously untaxed capital gains and fringe benefits into the income tax net, and lowered the top marginal rate from 60% to 49%. It is interesting to note in passing that the only reduction on the top rate of income tax in the last quarter-century has been implemented by a Labor government.

Second, the Howard Government's reform of the indirect tax system in 2000, which abolished the wholesale sales tax imposed on manufactured goods (at rates of between 12% and 45%) and replaced it with a goods and services tax (at a rate of 10%) applying to virtually all goods and services except basic foods, education and financial services.

And third, the Howard Government's reform of the business income tax system, which lowered the company tax rate from 36% to 30% and removed the accelerated depreciation provisions, between 2000 and 2002.

Australia's personal income tax system would be simpler, fairer, more efficient (in the sense of having fewer distortionary effects on the economy) and less prone to avoidance and evasion if all of the exemptions, concessions and deductions with which it is riddled were eliminated and marginal rates lowered: that is, if exactly the same approach were taken to reforming it as has been taken by governments of both major political persuasions to reforming other parts of the tax system.

It is indisputable that these exemptions, concessions and deductions *do* lead to substantial losses of revenue, cause significant distortions in the economy, favour high-income taxpayers at the expense of lower-income taxpayers (and thus detract from the equity of the tax system), and create opportunities of evasion or avoidance of tax.

Take, as an example, the practice known in Australia as 'negative gearing', under which taxpayers can offset the costs of borrowings undertaken to acquire an investment asset (such as a rental property or a share portfolio) against not only the income produced by that asset, but also against other taxable income such as their salaries. To the best of my knowledge no other country in the world is so generous to leveraged investments as Australia.

The appeal of negative gearing was greatly enhanced by the Government's decision in 2000 to halve the rate at which capital gains (on assets held for more than 12 months) are taxed. It is not at all obvious to me why capital gains should be taxed at a lower rate than income from wages and salaries, other than that this is also the case in some other countries. There's certainly no evidence that it has lifted the level of saving. Nonetheless, this decision was supported by the Opposition.

The halving of the capital gains tax rate effectively converted negative gearing from a strategy which allows tax to be deferred, to one which allows tax to be both deferred *and* reduced: for taxpayers in the top tax bracket, interest paid is deductible in the year in which it is incurred at 48½ cents in the dollar; while the capital gains which the borrowings help to facilitate are taxed at a time of the taxpayer's choosing (when he or she sells the asset) at 24¼ cents in the dollar.

According to the Tax Commissioner, in the 2003–04 financial year, 1.4 million Australian taxpayers claimed deductions in respect of rental property investments – an increase of more than 43% since the 1999–2000 financial year.[f] That represents nearly 14% of all taxpayers – a proportion which, according to the Reserve Bank, is more than double that of American taxpayers and more than six times that of British taxpayers.[g] In 2003–04, claimed deductions on rental property investments exceeded declared rental income by $2.6bn, a dramatic turnaround from 1999–2000 when income exceeded deductions by $174m. It is hard to believe that so many people would have so willingly entered into loss-making propositions but for the powerful incentive to do so provided by the tax system.

Not surprisingly, the introduction of this change led to a significant increase in the use of negative gearing. It is absolutely no coincidence that established house prices in Australia's capital cities rose by an average of over 70% during the following four years.

Nor is it any coincidence that, since the introduction of this change, the share of Australia's national income devoted to residential investment has been 1½ percentage points higher than in the preceding decade, and that in 2004 the share of GDP allocated to residential investment exceeded that devoted to productive plant and equipment for the first

time in Australia's history.[h] The only other OECD countries in which this has occurred are New Zealand and Spain.

Since that part of Australia's gross domestic investment which is not financed by domestic saving must be financed by adding to our foreign liabilities, it ought to be of some concern that the tax system provides such powerful incentives to invest in assets whose capacity to contribute to the servicing and ultimate repayment of those foreign liabilities is, for all practical purposes, zero.

Of course, rental property investors are not the only ones to avail themselves of the subsidies provided by the tax system through unrestricted negative gearing and the concessional tax treatment of capital gains. In all, some 930,000 taxpayers declared capital gains in their 2003–04 tax returns, and Treasury estimates that the revenue foregone as a result of those gains being taxed at half the rate applicable to other income amounted to over $2.5bn in that year.[i] Taxation statistics for 2001–02 indicate that two-thirds of the capital gains reported in that year accrued to taxpayers in the top tax bracket.

Negative gearing and the concessional tax treatment of capital gains are not the only departures from the principle of neutrality which favour high income earners. For example:

The concessional tax treatment of motor vehicles for fringe benefit taxes – which costs $1.1bn annually in revenue foregone – benefits those who take part of their remuneration in the form of employer-provided vehicles, a privilege much more readily available to more highly-paid employees than to those on lower incomes, at the expense of those who cannot or choose not to.

People over the age of 65 – for no reason other than that they are over the age of 65 – will by the 2006–07 financial year be able to earn up to $25,575 per annum as singles or $43,956 of as couples from investments before having to pay any income tax – an amount which would require income-earning assets of around $875,000 earning 5% pa – whereas people under that age (with no dependants) start paying tax on their wages or salaries at around $16,650 as singles and $30,500–$31,000 as couples.[j]

Deductions for work-related expenses – which totalled $10.7bn in 2003–04 – cost at least $3½-4bn in revenue foregone. CPA Australia puts this cost at $4.7bn,[k] Taxpayers in the top tax bracket, who accounted for 13% of all taxpayers, claimed 24% of these deductions.[l]

In total, Treasury puts the total cost (in revenue foregone) of 'tax expenditures' at $31bn in 2003–04 – equivalent to 22% of the total amount collected in income taxes from individuals, companies and superannuation funds – and suggests that this will rise to $39bn by 2007–08.[m] The modelling recently commissioned by Liberal MP Malcolm Turnbull suggests that flattening the income tax structure from the present 15/30/40/47% rate scale to a 15/30/35% scale would cost $5½bn; while a 15/25/35% scale would cost just over $15bn in revenue foregone[n].

Personal income tax reform based on lowering marginal rates and broadening the base by removing concessions, deductions and exemptions which are used primarily by high-income taxpayers to reduce and defer tax can thus be readily achieved without pushing the budget into deficit, and without requiring swingeing expenditure cuts.

One does not need to believe, or to argue, that lowering the top marginal rates of income tax will stimulate a torrent of additional work by high-income earners – I don't – or that it will prompt a mass return to Australia by 'tax exiles' currently working in (marginally) lower-tax jurisdictions such as the US or the UK – I don't – in order to believe, and argue – as I do – that a reform program based on lowering marginal tax rates and broadening the income tax base would improve the overall equity of the tax system, reduce compliance costs and increase the likelihood that investment decisions were based on a rational assessment of risk and return rather than on a desire to minimise tax.

Indeed, following the decisions in the most recent Budget to raise the top tax threshold to the point where only 3% of taxpayers will be paying the top rate from 1 July next year, it is difficult not to wonder whether the resistance to reforms of this nature stems from the fact that those who would be portrayed in the media as deriving the greatest benefit from such reforms (who are not necessarily those who actually would) live almost entirely in safe Liberal electorates in the big cities, or in the safe Labor electorates in the ACT, where their votes are entirely irrelevant to the government's prospects of re-election.

My answer to the challenge posed by the Treasurer to advocates of reform along these lines, 'who will pay for the reduction in marginal rates?', is: 'those high income earners who are currently using the various exemptions, concessions and deductions in the income tax system to pay less than the top marginal rate on at least some of their income which would otherwise be taxed at that rate'. In other words, I'm advocating a redistribution of income *among* the rich – in ways that I believe would be beneficial for the Australian economy – not a redistribution of income *to* the rich from those less well-off.

Indeed, if one were to abolish all of these loopholes, and to introduce a withholding arrangement for interest and dividend income similar to the PAYE deductions made from wage and salary income – which would not be too difficult since payers of interest and dividends are already required to collect tax file numbers from recipients of these payments and advise the ATO of the amounts paid – then it would probably be possible to relieve most individual income tax payers of the need to file an annual return altogether.

The ATO could send a statement to every taxpayer indicating what he or she had earned from wages and salaries, interest and dividends, how much tax had been deducted from that income, and the refund to which the taxpayer was entitled or the amount of additional tax which was owing. If the taxpayer wished to contest that statement, he or she would then file a return; otherwise, he or she would simply bank or write out a cheque (or the on-line equivalent thereof), as the case may be. Those whose circumstances changed significantly during any one year, and those with business income or other types of investment income (such as rent or capital gains) would obviously still need to be required to file returns; but overall the income tax system would be much simplified.

I can imagine that accountants would not care much for a reform along these lines; but I can't see why anyone else should object.

The same approach, could, incidentally, be applied to State taxation. At present, the second largest source of State tax revenues is stamp duty on land transfers. As State Governments have found over many years, revenues from stamp duty on land transfers are volatile – being dependent on both real estate prices and the volume of real estate transactions – and unpredictable. They also impose a heavy burden on people when, arguably, they are least able to afford it – when they are entering into what for most

people is the largest single financial commitment they will make in their lives.

Surely it would be both more equitable and, from the standpoint of State Governments, in the interests of better financial management, to replace stamp duties on the transfer of land with a more broadly based land tax. Instead of extracting large amounts of money from a small number of people (in any one year) occasionally, as stamp duties do, State Governments could extract smaller amounts of money from a large number of people regularly – as local governments do through municipal rates. Such a reform might seem politically 'courageous', in the sense intended by Sir Humphrey Appleby, but it is hard to believe that it could not be sold.

There is a lot more that I could say on this subject, including making the point that there are still serious anomalies in the interaction between the income tax system and the social security system which have much more significant adverse effects on labour force participation than the level of the top tax rate. But it is time to move on to my second proposition.

Proposition 2: there is something uncomfortably reminiscent of the former East Germany about the way in which Australia holds up success in sport as somehow indicative of the superiority of our way of life; and we pay a price for the fact that we do not regard success in other fields as similarly worthy of support, encouragement or pride.

Let me say straight up, since if I do not it will inevitably be presumed otherwise, that I do *not* dislike sport. Well, golf bores me senseless, and I'm in a way proud of the fact that I've lived in Melbourne for over 22 years without once having been to a horse race.[o] But I *do* like cricket and (Australian Rules) football. And indeed one of my fondest dreams is that during my lifetime we will actually have a truly national football competition, one in which *every* State is represented, and that I will see a Tasmanian team play in an AFL final series.

Nor am I opposed to the public funding of sport. There is a clear economic case for the expenditure of public money on encouraging participation in sport. Apart from the health benefits that accrue from regular exercise, participating in sports teaches the benefits of persistence and team work, the importance of rules and fair play, and (desirably) the capacity to lose with good grace. Even for those who are not active participants, sport plays a vital role in bringing together Australians who might otherwise have little in common.

Nonetheless, the fact that I like (watching) some sports as much as any other Australian (male), and that I readily acknowledge the positive role which sport plays in the lives of Australians, does not prevent me from observing that there is a Great Australian Double Standard at the heart of our national identity.

It is that the pursuit of excellence, the nurturing of talent (at public expense) and the recognition and financial rewards that accompany success are all applauded in the context of sport in Australia, but viewed with disdain in virtually every other field. Sport is one of only three socially acceptable ways to become rich in this country – the others being through popular entertainment or gambling.

Or take the word 'elite'. For an Australian to say of someone that he or she is an elite athlete or sportsperson is, in every context, intended and taken as a complement. But to say, in any other context, that someone is part of an 'elite' or is an 'elitist' is to aver that he or she is part of a privileged minority, out of touch with 'mains(h)tream Aus(h)trayans' (*sic*), and that his or her opinions on a subject are of no account whatsoever.

Recall the extraordinary outburst of wailing and gnashing of teeth which occurred after the 1976 Montreal Olympics, when Australia not only failed to win any gold medals, but – ignominy piled upon shame! – won fewer medals of any type than New Zealand.

After the ensuing outcry the Fraser Government established the Australian Institute of Sport, on which it and its successors have lavished ample amounts of public funds, and to which young people identified as having the potential to be Olympic champions are sent at public expense – with no requirement to make any repayment to the public purse of the cost of their maintenance and training via HECS-type arrangements as are the mere mortals who attend universities.

This financial year, the Australian Sports Commission (which manages the AIS) will receive $208m of funding from the Commonwealth Budget, an increase of nearly 140% from the $83m it received in the last year of the Keating Government (how many other agencies, other than security agencies, have had their funding more than doubled since the Howard Government came to office?).

This year's Commonwealth Budget provides an additional $41m over four years 'to support elite sport' (in what other context does the Howard Government explicitly support 'elite' anything?). It also provides a further $11m so that Australian athletes can spend time training in Northern Italy (what other instructional institutions have been assisted with taxpayers' money to establish an overseas campus?).

Contrast this with the reaction to the revelation two years ago that Australia had not one of the top 100 universities in the world. Rupert Murdoch and the Governor of the Reserve Bank, Ian Macfarlane, expressed concern about this less than gold medal-winning performance. But was there a national outcry? Was there a public inquiry? Was there an immediate injection of funds into our university system? No, there was a collective national yawn.

In fact last year the number of Australians attending universities declined, for only the second time in 50 years. To the best of my knowledge no one in government or business has thought this worthy of comment.[p]

Every year Interbrand produces a list of the top 100 global brands.[q] For each of the past five years, it has been topped by Coca-Cola, Microsoft, IBM and GE, in that order. Brands are the result of creativity and innovation. And brands are valuable: that's why anti-corporate 'activists' like Naomi Klein campaign against them. The top four global brands are valued at between US$67.5bn and $47.0bn. Not once in the last five years has there been an Australian name on this list.

Has this caused any kind of national outcry? Not at all. We take comfort in being told that we are 'too small' for any of our brands to be globally significant. But being smaller than Australia, the 16th largest economy in the world, hasn't prevented Switzerland, the 36th largest economy in the world, from having five on this list (Nescafé, Novartis, UBS, Rolex and Nestlé); the Netherlands, the 23rd largest economy in the world, from having three (Phillips, ING and Heineken); Sweden, the 34th largest economy in the world, from having one (Ikea); and Finland, the 49th largest economy in the world, from also having one (Nokia).

Australia produces a disproportionately high number of Olympic gold medallists, and other sporting champions, relative to our population, because our culture values and applauds success in that arena, and is willing to confer financial support and high social status on those who achieve it.

Conversely, we 'punch below our weight', to employ another sporting metaphor, in other areas such as the arts, sciences and business, because our culture does not value or respect success in these areas.

The Commonwealth, State and Territory governments spent $1.074bn on sport and recreation in 2000–01, the latest year for which such figures are available.[r] Local governments spent a further $1.05bn, nearly all of it on venues and grounds.

In the same year, the Commonwealth, State and Territory governments spent $1.559bn on 'the arts', plus another $226m on 'art museums';[s] figures for local government spending on 'the arts' that year are not available, although in 2003–04 local government spending on 'the arts' totalled $945m.

However, these figures for spending on 'the arts' include $914m spent by the Commonwealth Government on 'broadcasting and film', of which 90% represents funding of the ABC and SBS. Some of this is, of course, spent on broadcasting or televising sport: nothing wrong with that, but spending on 'the arts' it isn't. Nor does spending on news and current affairs, worthy and valuable though it is, constitute spending on 'the arts'.

It's not clear from their annual reports how much the ABC and SBS do spend on 'the arts', but it's not unreasonable to suppose that is of the order of 10% of what they receive from the Commonwealth. On that assumption, total spending on 'the arts' by the Commonwealth, State and Territory governments in 2001–02 was about $960m, $100m less than the amount they spend on sport.

According to a study by the US National Endowment for the Arts – which, admittedly, is now a little dated – Australian governments spend less per capita and less as a percentage of GDP on the arts than governments in any of a representative sample of 10 OECD economies other than the United States (where, of course, there is a much higher level of business and private support for the arts) and (rather surprisingly) Ireland.[t]

Yet the case for public spending on the arts is surely no less compelling than that for public spending on sport. Indeed, even President George W. Bush has acknowledged that:

> "the arts and humanities serve as an incomparable mirror and a record of humanity's response to the joys, tragedies, and mysteries of life. They help us better understand ourselves and our world. And they are essential to preserving and celebrating our democratic way of life."[u]

Economists understand this too. Maynard Keynes, in his last broadcast as Chairman of the Arts Council of Great Britain, ten months before he died, said:

> "The artist … leads the rest of us into fresh pastures and teaches us to love and to enjoy what we often begin by rejecting, enlarging our sensitivity and purifying our instincts."[v]

And of course (most) artists create something which continues long after their death, which (memories aside) is not the case with sportspeople.

The preference for spending on sport than on the arts is even more pronounced in the business sector than in the public sector.

In 2000–01, the latest year for which figures are available, Australian businesses gave $628m to sport and recreation by way of donations or sponsorship, representing 43% of their total donations and sponsorship expenditures, compared with less than $70m to the arts and culture (and, for that matter, compared with $339m to community service and welfare).[w]

This strong bias towards sport on the part of business people extends beyond where they spend their shareholders' funds. As Ralph Kerle of the Centre for Cultural Studies and Analysis points out:

> "rather than use arts as their inspirational role models for creativity, corporate leaders exhort their senior managers to embark instead on a quest to succeed and find new heights in performance by learning from Australian sporting heroes … a sporting champion and his *[sic]* mindset represent the least threatening metaphor for commercial innovation and creativity."[x]

Australian governments do spend more on research and development than they do on sport. In 2000–01 the Commonwealth, State and Territory governments spent $2.4bn on R&D – slightly more than half of it on plant or animal research.[y] Businesses spend even more on R&D than governments – nearly $5bn in 2000–01 – although they give much less to support R&D activities by way of donations and sponsorship than they do for sport. However, total Australian spending on R&D, including that by higher education institutions, is smaller as a percentage of GDP than 15 of the 27 OECD countries.

If anything, the tendency to exalt excellence in sport above excellence in any other field has increased in recent years. A search of the Australian Honours List[z] reveals that of the 22,154 ACs, AOs, AMs and OAMs awarded since their inception, 1,775 or 8.0% have been for 'services to sport' or to particular sports. This is in addition to the 18,002 recipients of the Australian Sports Medal. But in 2004, the proportion of the recipients of these awards who received them for sport was 10.4%; and in 2005 it was 15.8%.

Twelve of the 50 'Australians of the Year' since that award was instituted in 1964, and ten of the 26 'Young Australians of the Year' since 1979, have been sportspeople; in the past eight years, half of the 'Australians of the Year' have been sports people.

Let me conclude this discussion of my second proposition by emphasising that I do not begrudge successful sports people the support they have received from governments; or the social standing, high incomes and wealth which they have attained as a result of their achievements. I just wish that as a nation we were as willing to identify and invest in people with the potential to excel in the arts and the humanities, in the sciences, and, yes, in industry and commerce, as we do for people with the potential to excel in sports; and that we were as forthcoming in our recognition of, and as tolerant of the financial rewards that come to, those who do achieve great things in other fields. If we

did, there would be more of such people, and Australia as a nation would be much the better for it.

Proposition 3: Australian governments reacted to two of the great shocks of the twenty-first century (thus far) – terrorism and corporate malfeasance – in ways that have adversely affected the Australian economy without materially reducing the threat posed by either of these developments.

The first five years of the twenty-first century have brought two great shocks to the Western world of which Australia is firmly a part. The first of these is the terrorist attacks on New York and Washington of September 11, 2001, and the subsequent atrocities in Bali in October 2002, Madrid in March 2003, and most recently in London in July 2005. The second is the succession of corporate scandals which erupted in the United States in 2002 with the collapses of Enron, WorldComm, and other companies as a result of demonstrable malfeasance on the part of executives of those companies, and which have had parallels in other countries including Australia. To be sure, these corporate scandals have not entailed the loss of any lives. But they have certainly entailed considerable losses of wealth, including in some cases people's entire life savings, and – like the terrorist attacks – have occasioned a great deal of soul-searching.

One common factor linking both of these shocks is that governments in many parts of the world, including Australia, have felt compelled to be seen to be doing something about them.

Of course I am *not* saying they should have done *nothing* about them. What I do want to say, however, is that a good deal of what they have done about both of them has been either ineffectual, or counter-productive, or both.

In the aftermath of September 11, Australia's governments, like governments in other parts of the world, have introduced an enormous amount of legislation and regulation ostensibly designed to 'improve security' and reduce the likelihood of their citizens being killed or injured as a result of atrocities such as those which took place on that date.

We have been repeatedly told that our right 'not to be killed in a terrorist attack' trumps whatever other rights our governments believe must be circumscribed in order to uphold this right – although we are never told the bases on which our governments reach that conclusion, ostensibly because to do so might 'compromise' their intelligence sources. These sources are, presumably, the same ones that failed to warn our governments about September 11, October 12, or any of the other terrorist atrocities that have since taken place.

To the same end we are expected to endure tedious delays and in some cases humiliating intrusions into our personal spaces at airports, to tolerate increased surveillance by closed-circuit TV cameras at sporting arenas and in other public places, to accept greater scrutiny of our financial transactions, to have reduced access to public buildings such as our Parliament Houses, to pay more for our airfares and to have more of our taxes diverted to security agencies. And of course we are not supposed to complain about any of these things.

I *think* that I am more likely to die as a result of a terrorist atrocity than I thought I was before September 11, 2001 – although whether I objectively *am* more likely to die that way, or am simply more aware of the possibility, I can't really say. For what it's worth, I think that I, as an Australian, am (marginally) more likely to die in a terrorist incident as a result of Australia's participation in the war in Iraq – although that doesn't mean I think Australia was necessarily wrong to participate in that war, any more than I would have thought had I been alive in 1939 that it would have been wrong to participate in the war against Hitler because that made us more likely to be targeted by the Japanese.

However, I am singularly unconvinced that I am any *less* likely to die as a result of anything that any government has done since September 11, 2001 with the ostensible aim of reducing that probability. Indeed, I am a little troubled by the thought that I am now more likely to be shot in the head by trigger-happy police whilst innocently riding on the London Underground (or some other means of transportation) than I was previously.

It seems to me that the 'security' procedures on which governments have insisted at airports are a reaction to the *modus operandi* of previous terrorist incidents rather than in thoughtful anticipation of what they might do next. Thus, I'm sure that if Richard Reid had scratched his nose, rather than his shoes, on American Airlines Flight 63 from Paris to Miami on December 22, 2002, security officials would be shining laser beams up our nostrils every time we go to catch a flight rather than making us take off our shoes.

My scepticism about the effectiveness of most of these measures is reinforced by the observation that they are so inconsistently applied. If, for example, I wanted to blow up an aeroplane flying between Wynyard or Devonport (on Tasmania's north-west coast) and Melbourne, or to hijack such an aeroplane and fly it into the Rialto Building in Melbourne – and let me hasten to add I have no such intention – then I would face no greater obstacle to such an evil plan today than I would have on September 10, 2001. If, on the other hand, my conscience got the better of me during the flight and I abandoned my evil intent, then I and my bombs would be intercepted on entry into Tullamarine.

It's not clear to me why the lives of those passengers travelling between any of Australia's capital cities or between them and other cities such as Cairns and Townsville should be more worthy of protection from the evil depredations of terrorists than those travelling from Wynyard, Devonport or any of the other regional airports around the country – since cost seems to be no object at major city airports. But it does make me more than a little dubious about the real effectiveness of the measures which have been put in place at major airports.

One very apparent consequence of our governments' desire to be seen to be doing something in response to the events of September 11, 2001 is that, in airports and in many other buildings and facilities besides, there are now employed thousands of people who do nothing, except prevent those who are doing something from doing it as quickly and cheaply as they otherwise would.

Exactly how many thousands is not possible to say, at least in Australia, since our employment statistics are not available in sufficiently rich detail to draw any unequivocal inferences. However, US employment data, which are available in much more granular detail than is the case in Australia (and for free) indicate that the number of people employed as 'security guards' and in 'airport operations' (other than pilots, air traffic control, baggage handlers and check-in clerks) rose by 8.0% between June 2001 and June 2005, compared with an increase in total employment of

1.2% over the same period. I would be very surprised if the corresponding Australian figures were not of the same order of magnitude.

The same general observations can be made of governments' responses to the various instances of corporate malfeasance that have been exposed in the US, Australia and elsewhere in recent years.

It is an unfortunate fact of life that some people are dishonest, that some people are greedy, that some otherwise good people succumb to temptation and that some of these people end up in business.

No amount of legislation or regulation can prevent this, any more than the fact that murder has been a criminal offence carrying the most severe penalties permissible under the law since time immemorial has prevented murders from occurring. But it is also true that those who have been exposed as perpetrators of various corporate misdeeds have been charged, and in most cases convicted, under laws that were in existence before those crimes were committed.

Yet that hasn't stopped governments, including our own, from unleashing a torrent of new legislation and regulation with the purported aim of ensuring that such misdeeds can never recur.

I can't put this any better than my own Chief Executive Officer, John McFarlane, who last week said:

> "Just because some companies get into trouble with regulators it doesn't mean everyone else is likely to do so. Just because some companies go bust, it doesn't mean the system is broken. Failure of weak companies is a normal part of the market operating effectively. Unfortunately the response tends to be overreaction and proscriptive, and it is time to lighten up to the rules that really matter."[aa]

Sarbanes-Oxley (which is a law passed by the United States Congress, but whose provisions extend extra-territorially to any corporation whose shares are traded on a US stock exchange, or who issue securities in the US), our own CLERP 9, International Financial Reporting Standards (IFRS) and other recent legislative or regulatory impositions have required the employment of hundreds (if not thousands) of additional people to prepare thousands of additional pages of figures and statements which no one is going to read and will make no practical difference to the likelihood that corporate malefactors will be deterred or detected.

It may not be entirely coincidental that the upsurge in productivity-stifling regulation in the areas of security and corporate governance over the past four years has coincided with a dramatic reversal in productivity growth in Australia.

Output per hour worked in what the Australian Bureau of Statistics terms the 'non-farm market sector', the most widely used measure of labour productivity in Australia, rose at an average annual rate of nearly 3% over the decade ended the December quarter 2003. But since the March quarter of 2004, this measure of labour productivity has *fallen* by 2.5%. This is the first decline in this measure of productivity since 1986.

Some slowdown in labour productivity growth over the past 18 months or so would not have been surprising, since economic growth (as measured by real GDP) has slowed from 4½% pa to about 2% pa over this period.

Typically, productivity growth slows when the economy begins to slow, because most employers are reluctant to start laying off workers until they are sure that the slowdown is not a passing phase. However, the magnitude and duration of the divergence between economic growth and employment growth (which has accelerated from less than 2% pa to 3½% pa) over this period has been too large to be explained by the normal cyclical behaviour of productivity growth.

It is possible that the abrupt decline in productivity reflects an understatement of economic growth, for some reason, that may be corrected by future revisions to previously published data (employment statistics are typically not subject to significant revisions).

It is also plausible that the absence of any significant productivity-enhancing reforms since the industrial relations changes and waterfront reforms of 1998 could account for some slowing in productivity growth – although that does not really explain why productivity should have dropped so abruptly since 2003.

I would also accept that if the splurge of regulation relating to security and corporate governance had actually contributed materially to improvements in security and corporate governance, then a (hopefully) temporary setback to productivity growth might be an acceptable price to pay – just as I can accept that some loss of productivity growth may be an acceptable price to pay for improved environmental outcomes. But, as I have already observed, I am profoundly sceptical that the increased regulation in these areas has contributed to any meaningful improvement in security or corporate governance.

Rather, governments' responses to these issues suggests the re-emergence of an attitude that 'more regulation is the solution to issues that arise' (as John McFarlane put it last week), which I had rather hoped Australia had grown out of over the past two decades.

This evening I've strayed way out of my normal 'territory' as an economist, and made observations on matters where economists are not normally regarded as possessing any special insights – although I have sought where possible to buttress them by reference to evidence or to impeccable sources.

Perhaps in that context I can take some comfort from the view expressed by no less an authority than the Treasurer earlier this year that bank economists 'seem to be absolute experts on everything these days'.[ab]

But the unifying theme I have tried to weave through these three seemingly un-related propositions is that, in their different ways, they tell us something about our priorities, about our identity as a nation and as a society.

Do we really want to be a nation in which borrowing and speculation are more richly rewarded than working and saving, as our personal income tax system implies?

Do we really aspire to be a nation in which the only legitimate context for the pursuit of excellence is in sports, as the way in which our governments and our businesses allocate the funds available to them suggests, and as the way in which we confer honour and respect conveys?

Do we really wish to be a nation in which our citizens are subject to ever-increasing restrictions on our freedoms of movement, of speech, from covert surveillance, and from detailed regulatory oversight, so that our governments can feel satisfied that they are seen to be 'doing something' about every problem that emerges, as their responses to terrorism and corporate scandals suggest?

My answer to each of these questions is an emphatic no. But, as is often the case, I make no claim to be speaking on behalf of anyone else.

(Endnotes)

a Saul Eslake is Chief Economist of the Australia and New Zealand Banking Group Ltd. However, and to a greater extent than is usually the case, the views expressed in this paper are entirely his own, and do not purport to be (and should not interpreted as) representing those of his employer or any of its other executives.

b James Tobin, 'Autobiography' (1981), at <www.nobel.se/economics/laureates/1981/tobin-autobio.html>

c John Maynard Keynes, *The General Theory of Employment, Interest and Money* (London: Macmillan, 1936), p. 383.

d Paul Krugman (2000), 'Why I Am an Economist (Sigh) – Notes During Textbook Revision', at <http://web.mit.edu/krugman/www/Serfdom.htm>.

e Wayne Swan, MP, 'Bridging the Ambition Gap', Speech to the Investment and Financial Services Association (Sydney: 26 August 2005), p. 15.

f Australian Taxation Office, Compliance Program 2005–06, p. 10; Taxation Statistics 2002–03, Table 7.

g Reserve Bank of Australia, Submission to the Productivity Commission Inquiry on First Home Ownership (Sydney: November 2003), p. 19.

h These calculations are based on nominal rather than real values (so as to capture the impact on prices as well as volumes) and exclude the quarters affected by the introduction of the GST.

i Commonwealth Treasury, *Tax Expenditures Statement 2004* (Canberra: January 2005), p. 9.

j Kerrie Bremmer, 'Net tax thresholds for Australian Families', in Commonwealth Treasury, *Economic Round-Up* (Canberra: Winter 2005), p. 46.

k CPA Australia, Reforming Australia's Tax System – A Model for the Future (Melbourne: 2004).

l Based on calculations by John Freebairn, 'Income Tax Reform: Base Broadening to Fund Lower Rates', in Peter Dawkins and Michael Stutchbury (eds), *Sustaining Prosperity* (Melbourne University Press, 2005), p. 129 and ATO, *op. cit.*

m Commonwealth Treasury, *op. cit.*, p. 8.

n Malcolm Turnbull, MP, and Jeromey Temple, *Taxation Reform in Australia: Some Alternatives and Indicative Costings* (August 2005), pp. 19 and 46.

o Call me a spoilsport, if you will, but I am troubled by the fact that if a horse is any good it will generally be required to carry enough lead to prevent it from doing as well as it otherwise would. This apparently makes for more interesting betting, but it is hardly a test of a good horse. How interesting would the 400m or 1500m freestyle events be if Ian Thorpe or Grant Hackett were required to have 10 kilos of lead sewn into their lycra swim suits?

p It has been noted by Wayne Swan (*op. cit.*, p. 14), Jenny Macklin and Craig Emerson.

q See *BusinessWeek* online, <http://bwnt.businessweek.com/brand/2005/>.

r Australian Bureau of Statistics, *Sport and Recreation Funding by Government* (catalogue no. 4147.0, November 2002), p. 5.

s ABS, *Cultural Funding by Government* (catalogue no. 4183.0, August 2005), p. 6.

t National Endowment for the Arts, *International Data on Government Spending on the Arts*, Research Note #74 (January 2000), Table 1. The data in this study relate to the mid-1990s.

u At an award ceremony honouring recipients of the National Medal of the Arts, 22 April 2002.

v John Maynard Keynes, 'The Arts Council: Its Policy and Hopes', broadcast on the BBC, 12 July 1945; cited in Robert Skidelsky, *John Maynard Keynes: Fighting for Britain 1937-1946* (London: Macmillan, 2000), p. 294.

w ABS, *Generosity of Australian Businesses* (catalogue no. 8157.0, June 2002), p. 6.

x Ralph Kerle, 'We May Be the Lucky Country – but Not the Creative Country', *Company Director* (Australian Institute of Company Directors, October 2004), p. 16.

y ABS, *Research and Experimental Development – All Sector Summary* (catalogue no. 8112.0, September 2004). This publication includes figures for 2002–03 but I focus here on the 2000–01 data for consistency with the latest available for spending on the arts and sport.

z On-line at <www.itsanhonour.gov.au>.

aa John McFarlane, 'Challenging the Role of Corporations in Society', Address to the University of Melbourne 'Town and Gown' Dinner (31 August 2005), p. 11.

ab Hon. Peter Costello, MP, at a press conference in Melbourne on 27 April 2005: on-line at <http://www.treasurer.gov.au/tsr/content/transcripts/2005/048.asp>.

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